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TRANSACTIONS

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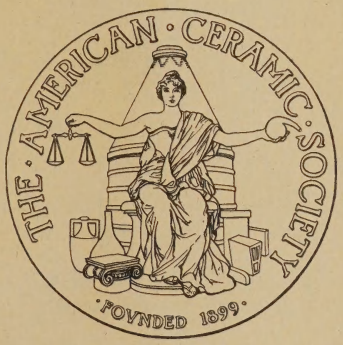
HOMER F. STALEY, *Editor*



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Gates, William P., Terra Cotta, Ill.	American Terra Cotta and Ceramic Company
Gladding, Augustus L., B.Sc., Lincoln, Calif.	Gladding, McBean and Company
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RULES OF THE SOCIETY

(Revised 1911)

I

OBJECTS

The objects of the American Ceramic Society are to promote the arts and sciences connected with ceramics by means of meetings for the reading and discussion of professional papers, the publication of professional literature, and for social intercourse.

II

MEMBERSHIP

The Society shall consist of Honorary Members, Active Members, Associate Members and Contributing Members.

Honorary members must be persons of acknowledged professional eminence, whom the Society wishes to honor in recognition of their achievements in ceramic science or art. Their number shall at no time exceed two percent of the combined active and associate membership.

Active members must be persons competent to fill responsible positions in ceramics. Only Associate Members shall be eligible to election as Active Members, and such election shall occur only in recognition of attainments in the field of ceramics, and interest in the Society, as evidenced by papers or discussions contributed to its meetings.

Associate Members must be persons interested in ceramics or allied arts.

Contributing Members must be persons, firms, or corporations who, being interested in the Society, make such financial contributions for its support as are prescribed in Section 3.

Honorary Members shall be nominated for election by at least five active members, and approved by the Board of Trustees. Their nomination shall be placed before the Society at an annual meeting, and to be elected they must receive the affirmative vote of at least 90 percent of those voting, by letter ballot, at the next succeeding annual meeting.

To be promoted to active membership, Associate Members must be nominated in writing by an Active Member, and must be seconded by not less than two other Active Members, and must be approved by the Board of Trustees. Their nomination shall be accompanied by a statement of their professional qualifications and a list of their publications, if any. Their nominations, when approved by the Board of Trustees, shall be placed before the Society at an annual meeting, and to be elected they must receive the affirmative vote of not less than 75 percent of those voting, by letter ballot, at the next succeeding annual meeting.

A candidate for Associate Membership must make application upon a

form, prepared by the Board of Trustees, which shall contain a written statement of the age and professional experience of the candidate, and a pledge to conform to the laws, rules and requirements of the Society. Such applications must be endorsed by two Active Members of the Society as sponsors, and must be approved by the Board of Trustees. The Board may act by letter ballot upon such application at any time, after which an approved candidate may be enrolled on the proper list of the Society upon payment of the fees and dues prescribed in Section 3.

Contributing Members shall be nominted by an Active Member, and approved by the Board of Trustees, and may be enrolled on the proper list of the Society at any time upon payment of the dues prescribed in Section 3.

All Honorary Members, Active Members, Associate Members, and Contributing Members shall be equally entitled to the privileges of membership, except that only Active Members shall be entitled to vote and hold office. The roster of each grade of membership shall be printed separately, in at least one publication issued by the Society annually. Any person may be expelled from any grade of the membership of the Society if charges signed by five or more active members are filed against him, and a majority of the Board of Trustees examines into said charges and sustains them. Such person, however, shall first be notified of the charges against him, and be given a reasonable time to appear before the Board of Trustees, or present a written defense, before final action is taken by the Board of Trustees.

III

DUES

Honorary Members shall be exempt from all fees or dues.

The initiation fee of Active Members shall be ten dollars, and if not paid within three months after the date of their election, the latter shall be null and void. The annual dues for Active Members shall be fixed by the Board of Trustees, and shall not exceed ten dollars.

The initiation fee of Associate Members shall be five dollars, and their annual dues shall be fixed by the Board of Trustees, but shall not exceed five dollars. The privileges of Associate Membership after election shall begin upon payment of the initiation fees, and dues for the first year.

Contributing Members shall pay no initiation fee into the Society. Their annual dues shall be fixed by the Board of Trustees, but shall not exceed twenty-five dollars. The privileges of membership shall begin upon payment of the annual dues.

Any Active Member or Associate Member in arrears for over one year may be suspended from membership by the Board of Trustees, until such arrears are paid, and in event of continued dereliction, may be dropped from the rolls. Active Members in arrears are not eligible to vote. The annual dues of Active and Associate Members are payable within three months succeeding date of annual meeting.

IV

OFFICERS

The affairs of the Society shall be managed by a Board of Trustees, consisting of a President, Vice-President, Secretary, Treasurer and three Trustees, who shall be elected from the Active Members at the annual meeting, and hold office until their successors are elected and installed.

The President, Vice-President, Secretary and Treasurer shall be elected for one year, and the Trustees for three years; and no President, Vice-President, or Trustee shall be eligible for immediate re-election to the same office.

The duties of all officers shall be such as usually pertain to their offices, or may be delegated to them by the Board of Trustees or the Society; and the Board of Trustees may, at its discretion, require bonds to be furnished by the Treasurer.

Vacancies in any office shall be filled by appointment by the Board of Trustees, but the new incumbent shall not thereby be rendered ineligible to re-election at the next annual meeting to the same office. On the failure of any officer to execute his duties within a reasonable time, the Board of Trustees, after duly warning such officer, may declare the office vacant, and appoint a new incumbent.

A majority of the Board of Trustees shall constitute a quorum, but the Board of Trustees shall be permitted to carry on such business as it may desire by letter.

V

ELECTIONS

At the annual meeting, a Nominating Committee of five Active Members, not officers of the Society, shall be appointed, and this committee shall send the names of the nominees to the Secretary at least sixty days before the annual meeting who shall immediately forward the same to the Active Members. Any other five Active Members may act as a self-constituted Nominating Committee, and also present the names of any nominees to the Secretary, provided it is done at least thirty days before the annual meeting. The names of all nominees, provided their assent has been obtained, shall be placed on the ballot without distinction as to nomination by the regular or self-constituted Nominating Committee, and shall be mailed to every member, not in arrears, at least twenty days before the annual meeting. The ballot shall be enclosed in an inner blank envelope, and the outer envelope shall be endorsed by the voter, and mailed to the Secretary. The blank envelopes shall be opened by three scrutineers appointed by the President, who will report the result of the election at the last session of the annual meeting. A plurality of votes cast shall elect.

VI

MEETINGS

The annual meeting shall take place on the first Monday in February, or as soon thereafter as can be conveniently arranged, at such place as the Board of Trustees may decide, at which time a report shall be made by the Board of Trustees, Treasurer and scrutineers of election, and the accounts of the Treasurer shall be audited by a committee of three, appointed by the President. Ten Active Members shall constitute a quorum at any regular meeting, and a majority shall rule unless otherwise specified.

The order of business at the annual meeting shall be:

1. President's address.
2. Reading of minutes of last meeting.
3. Reports of the Board of Trustees and Treasurer.
4. Appointment of committees.
5. Old business.
6. New business.
7. Reading of papers.
8. Announcement of election of officers, Honorary and Active Members.
9. Installation of officers and new members.
10. Adjournment.

Other meetings may be held at such time and places during the year as the Board of Trustees may decide, but at least twenty days' notice shall be given of any meeting.

The President shall appoint at the annual meeting a committee of five, to be known as the Summer Meeting Comm ttee, whose duty it shall be to arrange for a summer excursion meeting at some suitable point. The expenses of the Summer Meeting Committee in arranging the program of visits, and for printing, rooms and facilities for meetings shall be borne by the Society.

VII

PUBLICATIONS

The Board of Trustees shall employ, at suitable compensation, an Active Member of the Society as Editor of its publications. The Editor, together with the Secretary and Treasurer, shall constitute a Publication Committee. The Publication Committee shall provide for the publication of an annual volume entitled "Transactions of the American Ceramic Society." This volume shall contain a list of the officers, a list of members of the Society, classified into grades, a list of the ex-Presidents, the dates and location of meetings, the annual report of the Board of Trustees and Treasurer, the list of prices of the publications of the Society, the rules of the Society, and any other matter pertaining to the business administration of the Society

that the Publication Committee may think proper. It shall also contain such of the papers and discussions thereon as the Publication Committee may consider desirable, and each volume shall contain a list of the papers and discussions and an index. The volume shall be six inches wide by nine inches long, and part of the issue shall be bound in paper covers and part in cloth binding. The quality of the paper, the kind of type, the illustrations, and all other mechanical details of the printing and publishing of the books or reprints shall be in the hands of the Publication Committee, subject to the control of the Board of Trustees.

The acts and policies of the Publication Committee shall at all times be subject to the examination and approval of the Board of Trustees, but the Board shall be bound by contracts entered into by the Publication Committee in the name of the Society. The Publication Committee shall have full power and authority to decide what papers and discussions to publish, which discussions shall be germane to the subject matter, and in what order they shall be published, and in what manner and to what extent they shall be illustrated. In event that the Board of Trustees shall undertake the publication of some other matter or book than the Transactions, the Publication Committee shall act in the same capacity for that publication as in the publication of the annual volume of the Transactions.

One copy of the paper-bound edition of the Transactions shall be sent prepaid to each member of the Society not in arrears. Members desiring cloth-bound copies will be furnished them in place of the paper-bound copy at an increased cost for the binding. No member shall be furnished more than one copy of the Transactions free for any single year. Members cannot purchase extra copies of the Transactions at less than the current commercial rates. A member shall be permitted to purchase one complete file of the publications of the Society at less than the current commercial rate, the amount to be fixed by the Publication Committee and called the Member's rate.

The Secretary shall have the custody of all publications of the Society, shall keep them safely stored and insured, and shall sell these volumes to the public at prices which shall be fixed by the Publication Committee for each new volume as issued. The Publication Committee shall also, from time to time, fix the price of the old volumes remaining unsold, and shall have authority to refuse to sell the old volumes of the Transactions except in sets, at such time as the quantity remaining of any number becomes so small, as in their judgement to warrant such action.

The Editor shall request the author of each article appearing in the Transactions of the Society to fill out and sign, within a definite time limit, a blank form, specifying the number of reprints of said article, if any, which he desires. This form shall contain a table from which can be computed the approximate cost at which any reprints will be furnished. In event that the expense of furnishing the desired number of reprints is large, the Publication Committee may require the author to pay in advance for part or all of the cost involved before the publication of the reprints is begun.

On receipt of such signed order within the time limit set, the Editor shall cause to have printed the desired number of copies. If the author makes no reply, or replies after the time limit has expired, then the Society will not be responsible for the publication of any reprints of the article in question, except at the usual market price for the printing of new matter.

No one shall have the right to demand the publication of an article independent of the discussion which accompanied it, and no one having taken part in a discussion upon an article shall be entitled to order reprints of the discussion separately and apart from the article itself.

The Society is not, as a body, responsible for the statements of facts or opinions expressed by individuals in its publications.

VIII

PARLIAMENTARY STANDARD

Roberts "Rules of Order" shall be the parliamentary standard on all points not covered by these rules.

IX

AMENDMENTS

To amend these rules, the amendment must be presented, in writing, at the annual meeting of the Society, and must be printed on the ballot for officers and sent out not less than twenty days in advance of the next annual meeting, and if the said letter ballot shows an affirmative vote of not less than two-thirds of the total vote cast, then the same shall be declared carried.

PUBLICATIONS

The following is a list of the volumes published by the Society and the prices at which they are for sale to the general public:

Description of volume.			Bound in paper.	Bound in cloth.
Vol. I.	1899,	110 pages	$4.00	$4.75
Vol. II.	1900,	278 pages	4.00	4.75
Vol. III.	1901,	238 pages	4.00	4.75
Vol. IV.	1902,	300 pages	4.00	4.75
Vol. V.	1903,	420 pages	5.00	5.75
Vol. VI.	1904,	278 pages	4.00	4.75
Vol. VII.	1905,	454 pages	4.00	4.75
Vol. VIII.	1906,	411 pages	4.00	4.75
Vol. IX.	1907,	808 pages	5.00	5.75
Vol. X.	1908,	582 pages	5.00	5.75
Vol. XI.	1909,	632 pages	5.50	6.25
Vol. XII.	1910,	882 pages	5.50	6.25
Vol. XIII.	1911,	837 pages	5.50	6.25
Vol. XIV.	1912,	888 pages	5.50	6.25
Vol. XV.	1913,	... pages	5.50	6.25
Complete Set			70.50	81.75

The Board of Trustees established in the beginning a differential between members of the Society and others, in the matter of prices to be paid for copies of the Proceedings. This differential has been changed from time to time as volumes have grown scarcer and sales increased. The present arrangement, which will stand until March 1, 1913, allows a straight discount of 40 percent to members in good standing. Members in arrears are not furnished copies of the volume for the current year, nor allowed the discount for the older publications. Members are also not permitted to purchase more than one full set of the publications at members' rates. The care and sale of the Publications has been transferred to the Publication Committee, which reserves the right to change the discount from time to time on any one volume or on all, as may be necessary.

The number of copies of the earlier volumes is not large, and members are advised to procure full sets as soon as possible. The prices will never be less and will certainly rise as time goes on.

In addition to the above volumes of the Transactions, the Society has also published the following books, which will be sold *net* at the prices listed to the public and members alike:

The Collected Writings of Dr. Hermann August Seger, Volume I. Contains (*a*) Treatises of a General Scientific Nature. (*b*) Essays Relating to Brick and Terra Cotta, Earthenware and Stoneware, and Refractory Wares. Pages, 552. Bound in cloth..... $7.50

The Collected Writings of Dr. Hermann August Seger, Volume II. (*b*) Essays on White Ware and Porcelain. (*c*) Travels, Letters and Polemics. (*d*) Uncompleted Works and Extracts from the Archives of the Royal Porcelain Factory. Pages, 605. Bound in cloth..... 7.50

A Bibliography of Clays and the Ceramic Arts, by Dr. John C. Branner, 1906, 451 pages. Bound in cloth. Contains 6027 titles of works on Ceramic subjects..... 2.00

The above publications will be shipped at the consignee's expense, by express, to any address on receipt of the price. All checks or money orders should be made payable to the American Ceramic Society, and not to the Secretary or the Treasurer.

EDWARD ORTON, JR.,
Secretary.

Columbus, Ohio.

ANNUAL REPORT OF THE BOARD OF TRUSTEES

WASHINGTON, D. C., February 25, 1913.

To the Members of the American Ceramic Society:

The Board of Trustees report herewith the results of this year's work, the fourteenth of the Society's existence. It has been in all respects a year of growth and activity and its record constitutes an added claim to the good will and support of the ceramic industries and the respect and fellowship of the scientific world.

VOLUME FOURTEEN

The removal of Mr. R. C. Purdy from Columbus to Worcester, Mass., made it seem inadvisable to the Publication Committee to continue him as the Society's editor. The energy and ability with which he had conducted the duties of the position are known to all, and most of all were recognized by the committee, who had to take the responsibilityof securing a successor. The importance of keeping the editor's work in close relation to that of the Secretary at Columbus, seemed to be great enough to justify the step.

Professor Homer F. Staley was therefore appointed editor for Volume XIV, and the Society is in position to judge how well and acceptably he has performed his work in this maiden effort. The Society has not known however that he has labored under the severe handicap of having a very incomplete and inaccurate stenographic report—the worst that we have ever received. Had it not been for notes jotted down in long-hand by the secretaries of the two sections, it would have been wholly impossible to reconstruct some of the discussions. The credit due to Professor Staley for the excellent volume which he has produced is thereby much increased.

The volume itself is the largest thus far, not only by number of pages, but by matter per page. It is full of solid meaty articles, and has brought added recognition and prestige to the Society in both domestic and foreign scientific circles.

PUBLICATION POLICY

The policy always maintained by the Society in regard to printing articles from non-members as well as members, is certainly unusual among scientific and technical organizations. The grounds for it have been twofold.

1. The paucity of able contributors to literature in this field. The number of well trained men in the ceramic industries whose positions have been such as to leave them free to write of what they knew, has been small and still remains so. It has, therefore, been our constant effort to attract and bring into touch with us scientists working in all of the adjoining fields, such as geology, mineralogy, chemistry, physics, mechanical, mining and

chemical engineering, and so forth, whenever we found one of them whose interests had perchance strayed over the borders of his own domain and into that field which we have preempted and have been working diligently to cover.

2. Our conception of the Society's duty to the industries which it serves, has been that it should get together and put into print as speedily as possible the great body of knowledge possessed by those who are actually doing the ceramic work of the world, without much regard to the personal questions as to who is to receive the credit for it. Our industries are most of them old, and most of them have been and still are adminstered upon the mistaken policy of secrecy as a necessary condition to success. Very few practical ceramic chemists or work managers will tell what they know of their own branch of the industry. Some of them, however, have worked in different branches of the industry, and can be induced to tell their experience in a branch with which they no longer have connections; and thus by getting a little from one source at one time and from another source at another time, the whole great mass of technical knowledge is slowly but steadily being uncovered, assorted and recorded, and a literature worthy of the name is being created. This is the real raison d'être for this Society.

One cannot contemplate this plan without realizing that our duties are world duties, and not in any way restricted to the narrow circle of our own membership. It is, therefore, now, as in the past, the object of our Society to attract to its meetings and to the pages of its volumes, any and all who have anything new to say in this field. We want them as members, of course, if we can get them, as we need their financial help; but that is after all a secondary matter and by no means a ground for failing to secure and use their store of knowledge when it is open to us.

MEMBERSHIP

The membership has grown this year, but not so vigorously as before. The statistics are as follows:

Brought forward March 1, 1912:		
Honorary members	2	
Active members, resident	59	
Active members, foreign	4	
Associate members, resident	327	
Associate members, foreign	33	425
Accessions by election during the fiscal year:		
Active members, resident	3	
Active members, foreign	1	
Associate members, resident	55	
Contributing members	4	63

Losses during the fiscal year:		
By death, associate members	3	
By resignation or dropped fron non-payment of dues,		
Active members	2	
Associate members, resident	18	
Associate members, foreign	5	
By promotion, associate to active	4	32
Status, February 25, 1913:		
Honorary members	2	
Contributing members	5	
Active members, resident	58	
Active members, foreign	7	
Associate members, resident	352	
Associate members, foreign	32	456
Increase for the year		31
Percentage increase		7

The considerable number of losses during the year is a cause for regret. It is not to be expected, however, that as the Society grows older and larger, its entire membership can be held as firmly together by the ties of personal regard as was the case in its earlier years. There will of course always be some whose industrial affiliations change and those who do not longer find it profitable to maintain membership. It should be possible by another year to bring up our membership to the 500 point without resorting to active solicitation, or other undignified means.

FINANCIAL

The increase in dues and the opening up of a new source of revenue from contributing members has made this year the easiest through which the Society has passed since our work assumed anything like its present proportions. The increased rate for dues has met with no complaint from any quarter. The following is an analysis of receipts and disbursements:

INCOME

Brought forward from 1911–12		$97.82
Receipts from dues		
63 Active members for 1912 at $7.50	$ 472.50	
332 Associate members for 1912 at $5.00	1660.00	
4 Contributing members for 1912 at $25	100.00	
Various fractional payments for 1912 (mostly balances due from previous prepayments)	45.95	
Collection of dues in arrears	28.00	
Collection of dues in advance (1913)		
Active members	10.00	
Associate members	41.57	
Contributing members	25.00	
Banquet	15.00	2398.02

Receipts from initiation fees		
4 Active members at $10.00 (1912)	$40.00	
44 Associate members at $5.00 (1912)	220.00	
9 Associates prepaid (1913)	45.00	$305.00
Receipts from sale of publications		
Volumes of the Transactions	757.68	
Volumes of Branner Bibliography (5)	9.24	
Volumes of Segers Collected Writings (12)	90.00	
Extras from cloth bindings	127.00	983.92
Receipts from sale of reprints	208.81	208.81
Receipts miscellaneous	4.81	4.81
		$3998.44

DISBURSEMENTS

Publication of Volume XIV		
Stenographic Report	60.00	
Drawings, illustrations and engravings	512.33	
Printing, Binding and Casing	1521.36	
Editing (11 mos.)	550.00	$2643.69
Paid for Seger's Collected Writings	74.54	
Author's reprints	226.16	300.70
Paid for Administration		
Salary of Assistant Secretary (11 mos.)	275.00	
Postage, stationery and supplies	185.08	
Insurance	10.00	
Telegraph, Telephone	3.32	
Transportation of Transactions (express, freight, mail	234.21	
Binding early volumes for sale	35.00	
Convention expenses	49.08	
Loss on bad check	12.50	804.19
		3748.58
Balance in bank		249.86
		$3998.44

ASSETS

Cash in Bank		$249.86
Accounts Payable		
Dues and fees, due but not collected	$ 252.50	
Publications sold and not yet paid for	127.35	
Reprints sold and not yet paid for	16.64	396.49

Books on hand		
1952 Volumes of Transactions at $3.70	$7222.40	
Inventory of stock, stationey, fixtures, etc., est.	100.00	$7322.40
Total assets		$7968.75

LIABILITIES

None other than ordinary current accounts.

This statement shows that the Society is in a good sound condition though still working on a very conservative scale of expenditure. The new plan of asking that all dues be paid promptly within the first three months of the fiscal year, met with a fairly general obsevance, and made the work of collection easier than ever before. There was still, however, a considerable number who did not pay promptly and some who have not paid at all, and this has, of course, resulted in dropping a considerable number from the rolls.

For the current year, the plan of collecting dues from all who attended the meeting is being tried, and an additional effort to get the annual dues in promptly will be made.

SALES OF PUBLICATIONS

The inventory of our stock of volumes shows as follows:

NUMBER OF THE VOLUME	NUMBER REMAINING ON HAND FEBRUARY 1912	RECEIVED SINCE	DISPOSED OF BY SALE	DISPOSED OF OTHERWISE	IN STOCK FEBRUARY 1913, BY BOOK COUNT
I	178		11		167
II	151		14		137
III	176		11		165
IV	148		9		139
V	116		9		107
VI	144		8		136
VII	145		8	1 Dr. B	136
VIII	136		6		130
IX	100		8		92
X	128		6	1 Dr. B	121
XI	149		7		142
XII	135		10	1 Dr. B	124
XIII	244		21		223
XIV		704	549	22	133
Branner Bibliography	813		5	6	802
Balances	2763	704	682	31	2754

The stock of volumes remains approximately constant, the shrinkage by sales of the old volumes being just about covered by the excess supply of the new volume. A glance over the last column shows that there are now left less than 100 sets, and only about 125 nearly complete sets could be furnished. Members who have not yet procured a complete file are advised to do so while there is yet time.

INTERNATIONAL AFFILIATIONS

According to the plans proposed at the thirteenth meeting, the Summer meeting was arranged so as to be coincident with the trip of the members of the Deutcher Verein für Ton-, Zement- und Kalk-Industrie who were in America for the meetings of the Eighth International Congress of Applied Chemistry. Circular No. 6 (Series 14), issued August 19, 1912, announced this plan to the membership and their response was quite satisfactory.

The American Ceramic Society members to the number of about 30 met the German Society members to the number of about 18 at their hotel in Pittsburgh, on Saturday evening September 14, and escorted them to the Fort Pitt Hotel and enjoyed a delightful banquet together. Speeches were made in both languages expressing the need of a closer bond of acquaintance and co-operation.

This function was the only one in which the two Societies met with any formality, but members of the American Ceramic Society met and escorted the visitors at Pittsburgh, East Liverpool, Zanesville, Columbus and Chicago. The German delegates have expressed on frequent occasions and in various ways their appreciation of the courtesies extended, and without doubt the incident has created a much more cordial relation than has existed previously.

One more or less direct result of this meeting has been a proposal emanating from the German Society, that the presiding officers of each society shall be elected to membership ex officio in the other. The Board of Trustees concurs in the sentiment involved in this plan, and if a method can be devised in harmony with our rules, or that can be legalized by a simple amendment, would like to put such an arrangment into effect, not only for the German Society, but for the English Ceramic Society as well. The Board would appreciate an expression of opinion from the Society upon this topic.

SUMMER MEETING

The Summer Meeting last year being merged with the visit of the German delegates, did not take the place of, or fulfill the real function of this part of our work. It becomes of increased importance, therefore, that the present summer shall not pass without an excursion trip being energetically organized.

CONCLUSION

The Board desires to express the hope that the coming year will prove a more active and vigorous one than the last, and that each member of the Society shall not feel himself absolved of personal obligation to do his share to make it so.

Respectfully submitted,
THE BOARD OF TRUSTEES,
By Edward Orton, Jr.,
Secretary.

PAPERS AND DISCUSSIONS

PRESIDENTIAL ADDRESS

BY ARTHUR S. WATTS

The American Ceramic Society is opening its fifteenth annual meeting, and it seems fitting that at least brief mention be made of the attainments of the Society.

At the first regular meeting, held at Columbus, Ohio, in 1898, eight papers were presented, and during the year 23 active and 33 associate members were enrolled, making a total membership of 56. Our present meeting opens with 73 active and 398 associate members, making a total membership of 471. Our last volume contains 70 papers, and our next bids fair to equal if not exceed that number.

Our literature has become more technical from year to year until the question arises whether or not we are slowly altering from a society for the discussion of ceramic topics of general interest to one for the presentation of papers many of which are too highly technical to permit of any discussion or of an oral presentation.

A cause for great encouragement, however, is the fact that, as our papers have become more highly technical, our membership has grown with them; and we have never had the embarrassment of our audiences becoming fatigued from the fact that they could not understand, in a general way, the data presented.

One point which I think worthy of mention in connection with our more scientific articles is the desirability of drawing at least some practical conclusion from the data presented. Few articles have appeared in our *Transactions* which have not a practical application, but many of them are not expressed in terms which the average clay worker will understand. If the practical application is woven into the article, he will see the importance of acquainting himself with data presented, which he might otherwise condemn as purely theoretical.

Probably the great problem that confronts our managing board is how we may obtain papers from our practical members. When approached on the subject, they reply that they have no time to prepare a paper or that in their business they do not work out

problems in such form that they are presentable. To these statements the reply can be made that hardly a subject has been treated in our *Transactions* in a complete form. A member presents an introductory article and, another year, comes forward with some additional data along the same line. The fact that the subject cannot be treated exhaustively need not prevent the contribution of such data as is available. The discussions arising from the presentation of very short papers have often proven of more value than some of our most elaborate contributions.

It hardly seems advisable at this time to go into the discussion of the aim or object of our Society, and data regarding its growth is presented annually in reports by the Secretary and Treasurer. With your permission, therefore, I shall offer you as a substitute for a presidential address a paper which is practically a continuation of an article that I contributed last year.[1]

Before presenting this paper, however, I wish to thank the members of this Society for the great honor which you have conferred upon me in permitting me to serve you as president. The small amount of labor which falls to the president has been a real pleasure; and when, at the close of these meetings, I become once more one of the rank and file, I know that the hearty co-operation accorded me will be given in equal measure to my successor.

[1] The paper referred to is "Feldspars and a Deformation Study of Some Feldspar and Feldspar-Quartz Mixtures" shown later in this volume.—EDITOR.

THE GEOPHYSICAL LABORATORY

BY DR. A. L. DAY

INFORMAL ADDRESS DELIVERED AT THE OPENING SESSION

Mr. President and Gentlemen of the Society: I am not quite sure that we shall find common ground at once, from which to discuss the researches which have been undertaken by the Geophysical Laboratory, but it will perhaps serve as well if we can come to a clear understanding of the difference between our respective viewpoints; if we frankly recognize certain boundaries which we severally set for ourselves when we undertake any one of these silicate problems. I suppose an appreciation of the limitations of a field of study has as much to do with the successful prosecution of research in it as any other one quality which the student may possess.

We start, perhaps, from the same premises. The Geophysical Laboratory is trying to apply physics and physical chemistry to the silicates, and most of you, I fancy, are undertaking the same thing. But the Geophysical Laboratory endeavors, in each reaction to reach what we call the condition of *equilibrium;* that is to say, to carry on the reaction to a point where, for a given temperature and pressure, no further change occurs. Such a state is obviously capable of definition; it is a condition to which we can return again at any future time; it is a point also where any future observer may check the details as well as the published results of our research. Now that is a somewhat difficult matter with silicates, as most of you know, for the reason that they are so slow in their reactions that it is not always possible to reach this stable, definable condition within the limited time available for a laboratory experiment.

I think that in the technical branch of the industry you are concerned rather with problems of sintering in the body of your material, and in the glazes, you are concerned with preventing crystallization—both conditions being almost diametrically opposite to the one toward which we work. We are particularly concerned to carry the reaction through to a definite conclusion,

capable of definition and future repetition; that is, to a completely crystallized system and equilibrium.

We might go somewhat further into detail. For example, you may take two silicates and mix them in any proportion, melt them together and allow them to crystallize. Out of that mixture, there may crystallize either the one component which chances to be in excess or both components together in what we call solid solution—which by the way is not a glass but a series of mixed crystals. If one component comes out in excess, the mixture which remains is changed in composition, i.e., it will be poorer in that component and gradually approaches what we know as an eutectic mixture, which, although not a compound, is a definite mixture with fixed properties, to which we may also return for purposes of definition if we will. This series of changes, of course, is capable of definition at both ends and at the eutectic point and with a characteristic rate of change in the passage from one to the other.

If we had chosen two silicates which do not form an eutectic, let us say the lime and soda feldspars, and mixed them together in any proportion, we should have found two components capable of existing together in all proportions, either as glasses or as crystals. If you cool a melted mixture of these feldspars, out of it you will get not a single component in excess, but always a mixture of both components. The mixture may, in general, be stable or unstable according to the rate of cooling, but if a feldspar like albite or orthoclase is present in large quantity you cannot crystallize it within the time available for an ordinary laboratory experiment. It is then exceedingly difficult to speak of equilibrium at all for there is no point in the history of such a molten feldspar to which you can return with any certainty of reproducing exactly the same condition again.

So, when I say we differ somewhat in our viewpoints in approaching the silicate problem, it means substantially this, that we in the Geophysical Laboratory are dealing with the relations of crystalline minerals which either are in or can be brought to a definite equilibrium. I think this is not true in general in the silicate industries. You are dealing with a process in which the most important factor is the rate of change and not the end to

which the change would proceed if allowed to do so freely. You cannot, therefore, apply unlimited temperature; or you would melt all your porcelain to glasses. It is specifically necessary to limit both the time and the temperature to which a given composition is exposed in order to bring out your product exactly where you require it; and the repetition of exactly those constants of time and temperature, together with the same initial composition, are the only guarantees which you have that the end products will be the same. There is nothing in the material itself which guarantees the same end product unless you can reach what I choose to define a few minutes ago as a condition of equilibrium.

Now, it is obvious that I cannot speak of methods without speaking of purposes, because the method will only have value in connection with the purpose it serves. I have, therefore, given this very brief outline of the attitudes of mind with which we have approached the silicate question in order to show the purpose of the methods we use, and perhaps incidentally to explain that they may not serve your purpose equally well. Neither is it possible in an address of this kind, to take up in detail all the methods capable of application in so extended a field. The field is still comparatively undeveloped, and it is still necessary for us to feel our way gradually in these new directions, and to devise new methods and apparatus as we go along.

In general, the organization of the Geophysical Laboratory is simple. Chemistry must guarantee for us the purity of the materials that go into our melting pot. Physics must guarantee to us the conditions of pressure and temperature through which these materials pass. The product then passes into the hands of the mineralogist, who compares the output of our furnaces with corresponding natural minerals for purposes of identification of crystal form and habit; or it may pass into the hands of the physical chemist, who will endeavor to establish its relation to a general system of solutions. This system of mineral solution is, in the last analysis, the science of mineralogy, but only a very small portion of it is yet accessible to physical chemical experiment.

Now, it is not so much a question, in the technical handling of these silicates, of getting high temperature, there is no difficulty about that, as a rule; we shall always be able to get more temper-

ature than we can take care of. Much more important is it to measure the temperature exactly in order always to be able to return to it, also to define the composition with great exactness, and also finally, in the case of slow moving silicates, to be quite sure that we have reached this state of equilibrium which is capable of exact definition and, therefore, always offers a landmark to which we may return with certainty. Our equipment then, includes a chemical laboratory—four of them, in fact—a physical laboratory, although physics enters into nearly every stage of our processes; a physical-chemical laboratory, and finally a mineralogical laboratory.

The progress of the work of the Geophysical Laboratory has been the development of accurate physico-chemical methods for handling silicates, of which, until recently, but few were available except such as have been developed in the Geological Survey and kindred institutions, for purposes of analysis. The more general methods of treatment of the chemical relations of silicates requires to be done ab initio.

On the physical side, it was necessary to lay down a definite scale of temperature and to devise appropriate methods for making temperature measurements in these silicate solutions. That was a fairly straight-forward matter, and was completed three or four years ago.

Then the mineralogical methods were found to be wholly inadequate. We have had to devise practically new methods throughout for the measurement of crystals and their indentification, and this for the reason that the product which comes out of a small crucible in an electric furnace is quite different from the great natural crystals which adorn your museums. Nature had lots of time to wait for big crystals to form, and we have not. As a rule, we must confine ourselves to the time of one working day, or perhaps two. On special occasions, for important experimental work, we have kept furnaces at a constant temperature, within something like three degrees, for as much as thirty days at a stretch. Obviously, this kind of thing is experimentally difficult; break downs and disappointments frequently occur, and the expense is not inconsiderable; but if the need arises, it may be of interest to know that it is quite possible to maintain a temperature

of 3000°F. constantly for any experimental purpose likely to arise. In general, then, we have had to work rapidly or comparatively so, and our products, as a consequence of this, are made up of units so small that we could do very little with them by the ordinary methods of microscopic analysis. Where we are obliged to deal with crystals but two or three hundredths of a millimeter in their chief dimensions, obviously it will require a microscope to find them, to say nothing of the difficulty of measuring their angles and determining their optical properties. Therefore, it has been the task of a considerable staff of men in the Geophysical Laboratory, covering a period of seven years, to devise appropriate methods by which crystalline products of our furnaces could be competently studied when the dimensions of individual crystals do not exceed 0.02 or 0.03 of a millimeter in their chief dimensions.

This has been done, and now that it is done, the immense importance of the petrographic microscope in all questions of silicate analysis stands out as a most conspicuous result. Where you can use the microscope, it is enormously more rapid than any possible chemical method. You require to wait for no reactions; you do not require even to prepare your material more than to break it up into comparatively small fragments and put them under the microscope. Then oftentimes a glance or, at most, some very rapidly made measurements are quite adequate to determine all you need to know about the product. I cannot, therefore, say too much of the value of the microscope in all work which involves silicates, particularly in view of the fact that I know that the microscope is comparatively little used, thus far, in the silicate industries.

I do not know that I need to go into a detailed account of special problems which we have taken up. Those of you who are interested probably know them already, and those who are not, know where to find them in case you should desire to become more familiar with the details.

For the rest, it is perhaps better to say no more than that the Laboratory will be open for your inspection on Friday, whenever you find it convenient, and we shall be delighted to answer any questions which may arise in connection with your visit.

I should, perhaps, say a word in advance to avoid what may

otherwise prove a disappointment to you. If it is desirable, for reasons already intimated, to work under exact conditions of temperature and of composition, it is very necessary that the quantity of a material be not so large that it will project out of the windows of your furnace, so to speak, for the exposed portions will be at some other than the measured temperature. As our experience has increased, therefore, we have reduced the amount of material in a single charge from 100 grams down to 1 gram or even a fraction of a gram that you could hold on the end of your little finger without trouble. We can almost certainly guarantee to put that quantity through a uniform temperature every time. When it comes out, therefore, we are never in any doubt about the physical conditions which prevailed at the time when we were studying it. Our charges are, therefore, small and our furnaces are not impressive to look at.

You will perhaps share the experience of an Englishman who visited the Laboratory a year or two ago, who was particularly interested in an investigation of Portland cement which we had been conducting. I think he came with the idea that if he could but get into the Geophysical Laboratory, all the mysteries of cement making would promptly be solved. We showed him absolutely all we had, half a dozen furnaces, some electrical temperature measuring devices and about five thousand small bottles arranged on the wall in the order of the compositions of the cement samples. There was nothing more. The materials which we use, being, for the most part, prepared in the Laboratory from chemically pure materials, are almost invariably clear white without the slightest trace of color of any kind; and, therefore, the five thousand bottles, which represented our investigation of Portland cement, were as nearly identically alike as any series of preparations possibly could be. It was a great disappointment. In all such work, the need is not to use large quantities, big furnaces, roaring gas blasts, and what not, but rather to have all the factors accurately controlled and measured, and your visit to the Laboratory will certainly afford you an excellent illustration of this. I shall, therefore, be glad to welcome you on Friday at your convenience, and I thank you for your attention. (Applause.)

THE WORK OF THE NATIONAL BUREAU OF STANDARDS

BY DR. S. W. STRATTON

INFORMAL ADDRESS DELIVERED AT THE OPENING SESSION

Gentlemen, I understand that we are to have the pleasure of a visit from you at the Bureau of Standards Friday morning, and that a number of our specialists are to appear on the program, hence it will hardly be necessary for me to take up your time in going into the details that you will see at the Bureau, or in explaining the technical work along the lines in which you are interested, because it will be very much better done by Professor Bleininger and others who are on the program.

I might say very briefly that the work of the Bureau of Standards classified as to functions, involves the testing of standards, standards of measurement, and the solution of problems that are connected with standards of measurement; the determination of physical constants or standard values which are used in scientific work and industries, and the determination of the more specific properties of materials which will enable them to be more intelligently and more economically used. Now this classification has to do only with the functions; the organization of the Bureau is on an entirely different plan.

The first division is devoted to mass, length, capacity and time. Of course density and volume would fall in this same line of work. Now a standard of length, whether it be the precision standard used by the scientific man or the steel tape used by the engineer, would go to this division to be compared with the Government standards. The determination of the co-efficient of expansion of a material would be considered as a length measurement. The determination of the density or specific gravity of a substance would go to this same division. In other words, the same division handles work along all three of the lines mentioned. The organization of the scientific work of the Bureau is along the lines of the divisions of physics and chemistry.

The second division is devoted to electricity; and here again this involves the handling of electrical standards, which is a very difficult problem because there are many of them. These stand-

ards must be prepared from definitions and the apparatus must be devised with which to compare these standards with the standards of manufacturers. A few years ago the American Institute of Electrical Engineers asked the Bureau to determine the conductivity of commercial copper wire. This is used by engineers generally in the designing and construction of electrical machinery; this is a very good illustration of a physical constant determined by the electrical section. Materials are frequently received for the determination of their electrical properties, but by far the larger part of the work in this, as well as the other divisions, is in the nature of researches undertaken to determine fundamental constants of measurement or the fundamental properties of materials.

The third division is devoted to heat and thermometry. A large part of the work consists of the standardization of the various heat measuring instruments, also heat constants such as specific heat, latent heat and melting points. Recently the American Association of Refrigerating Engineers asked the Bureau to determine the heat constants needed by that industry. Congress has made a special appropriation for this and the work is well under way. It is exceedingly difficult work, as all heat measurements are; it is a good illustration of the relation of the work of the Bureau to that particular industry.

The fourth division is devoted to problems in optics. One would scarcely realize the important application of optics in the industries. In spectroscopy we are continually called upon to examine materials and to determine their nature by means of the spectroscope. One problem that frequently comes up is the determination and study of the absorbing power of different media. For example, the glasses used by operators of search lights—it is necessary that they absorb the violet and ultra-violet rays. The Bureau has had a great number of signal glasses to examine. Standards of color and the instrument for measuring color are greatly needed. The question of color determination has arisen and has come from a great many industries, including those in which you are interested. The measure of color in pottery and porcelains, in butter, paper, textiles and tobacco—there is an exceedingly great demand for a reliable method of measuring color and the Bureau is endeavoring to solve that problem.

The fifth division is devoted to chemistry. One reason why

foreign bureaus of this kind have failed to go quite as far as they should is that they have not properly related chemistry with the physics of these problems. We find that in every section and almost every problem taken up we must call upon chemists. We have a very excellent chemical division under Dr. Hillebrand and the other sections, technical as well as scientific, all lean upon him and his corps of chemists.

The sixth division is devoted to engineering investigations and the testing of engineering instruments. The seventh division is devoted to the determination and study of the properties of materials. In that division we have the sections devoted, first, to metals and their alloys; second, to cement, stones and so on; third, ceramics; fourth, miscellaneous materials, such as textiles, paper, rubber, etc.

I do not wish to take up too much of your time, but outside of the regular standardization of both quantity and quality, in which you are very well posted, there is another phase of the Bureau's work which is very gratifying; that is the cordial relation that has sprung up between the industries and the Bureau. Some of our industries are very progressive and are very apt in the application of science; others are not so well along. I have been astonished to find how backward some of the industries are in the application of scientific methods. Scarcely a day passes that we do not have several visitors from the various industries, all asking some important question about measurements or about the means of investigation. The outcome of this is that the industries are learning very rapidly, even those that are more backward than the others are learning the value of investigation. We try to set an example in this respect, and it would surprise you to know of the number of industries which have established research laboratories recently, and the great demand there is for men competent to carry on these investigations—not engineers, but physicists and chemists, especially physicists. The Bureau has lost several of its men in the past year, who left to go into manufacturing establishments. It is almost impossible to keep men, owing to the great and rapidly increasing demand for men who can perform research work in connection with the industries. I thank you very much for your attention and hope to see you at the Bureau Friday morning. (Applause.)

PROBLEMS IN SILICATE CHEMISTRY

BY DR. F. W. CLARKE

INFORMAL ADDRESS DELIVERED AT THE OPENING SESSION

Mr. President and Gentlemen, I am afraid that I am here under some misapprehension. I am expected to tell things which I do not know, and I have a large and varied assortment of that kind of information, which would take much more time to relieve myself of than I am at liberty to spend. It occurred to me, in thinking over the topic assigned by Professor Orton, that I could best say a little about the work going on here in certain lines that I know about in Washington, and its purport and significance, because I cannot tell you specifically very much about the clays, although, in a purely mineralogical sense I know something about their nature and composition. I do not know, however, how they individually act in certain industries, and I am a little skeptical about the help chemistry can give in that direction. In the Geological Survey, we have occasion to make a number of clay analyses but not a great many of them, and I am inclined to think that their utility is greatly over-rated. You may find two of the same chemical composition and one will do well and the other will not do so well. People may put clay in the kiln and see how it burns, then analysis may tell them why, but I am very skeptical as to the real value of the enormous number of clay analyses that are published in the various reports. I may be wrong, but that is the impression I have gathered.

There are three institutions in Washington which have something to do with these questions of the nature of minerals and the way in which they break down into clays. There is the Geological Survey, which approaches the subject from two points of view, the purely economical, as represented by our division of mineral resources, and the purely chemical, as represented by such work as can be done in the laboratory in my charge. There is the Bureau of Mines, which also touches the subject from another point of view, and the Geophysical Laboratory of the Carnegie Institution. The work in which I am particularly interested is entirely non-

technical; it is in the interest of pure science; and, as I have said many times before in gatherings of this general character, especially where men whose interest is from an entirely practical point of view are present, you cannot have any applied science unless you have the science to apply. So some of us must devote ourselves to the purely scientific side and others to the application of the knowledge which can be so obtained. There are no hard and fast lines between the two. Many and many a technical man is working in a purely scientific manner, but the division is one which expresses a definite idea and so far it may hold.

Now, looking at the thing from the purely scientific point of view, we find that every mineral has what you might call a life history. You take a feldspar. It is born from a fiery magma, and they are making them in the Geophysical Laboratory to-day. It is a beautiful crystalline mineral. That mineral is acted on by air and water and gradually decays, so that you have ultimately the death of that particular mineral in the form of a clay which is buried in the earth, and has a resurrection in the form of brick, or may even be glorified in the form of porcelain. This life history interests me. How does the mineral come into existence? How does it go to pieces?

The more I have considered the group of minerals known as clays, the kaolinite, montmorillonite and perhaps a dozen others, the more I think of them and study them, the more I am convinced that I know very little about them. I thought I knew something at one time, but I have come to the conclusion that the amount of my knowledge is extremely small. Take, for instance, the breaking down of feldspar into kaolinite; you will find in the books and in various published papers elaborate explanations of the mechanism of that change. You will find quite nice looking chemical formulae written out to explain the breaking down of feldspar into kaolinite. I think all those formulae are purely imaginary; there isn't one of them I have found which represents actual knowledge on that subject, and it seems to me that it is the function of the pure chemist to find out what the reactions actually are—to write out an equation which shall be true and rest on experimental evidence.

I think if we get information of that kind, we shall be able to

help the ceramic industry much more than if we make innumerable analyses of clays and pay no attention to their physical characteristics. One clay may be plastic while another, apparently of the same composition, is not; and a good deal of work has been done by various people to determine the cause of plasticity or non-plasticity. Mr. Cushman, of this city, has done a great deal on that line with reference to the use of different varieties of stone in road making, and has found out that plasticity depends very largely on the content of colloidal substances which bind, whereas the purely crystalline substances will not.

As to the various other things which are used in the ceramic industry, I am not qualified to express an opinion. I know perfectly well that all sorts of additions are made to the clays in the manufacture of porcelain, glass, brick, etc., but as to their respective functions, I am not qualified to express an opinion. The subject deserves a very large amount of investigation and I sincerely hope that where you are so situated as to be able to encourage research work, you will do so. Some of you are connected with universities and some of you are engaged in works near universities; and if you can persuade the men in charge of laboratories in those institutions to do accurate work in the interest of pure science which will help ultimately your applied science, you will get forward a great deal faster than you have done hitherto. The field is a big one and I should sincerely like to see some thoroughly good work done on the whole group of clay bodies and their real chemical and mineralogical nature determined.

There are two controversies on hand just now; one is as to the nature of the species called clays. You will find that in Europe, Thugutt, Stremme, and Le Chatelier are entirely at odds as to which are the true species and which are not. They agree upon a few like kaolinites and pyrophyllites perhaps, but there are others which they insist a remixtures of hydroxides and silica in the colloidal condition and are not true compounds at all. We don't know. It is the same way as to the origin of kaolin; there is a controversy going on there. Roesler in Germany has been elaborately arguing that it is produced from feldspar by the action of hot springs, volcanic action only, and we in this country feel pretty sure that the great deposits in the South and along the

Appalachians are due to the decomposition of feldspars by percolating waters, without any action of a volcanic character whatever. That illustrates the old saying, attributed to Macaulay, that the truth is neither black nor white but gray.

I might illustrate the controversy by a parable. A philosopher came from New York to Washington over the Pennsylvania Railroad, and found there some three hundred thousand people. Being a philosopher, he undertook to account for how three hundred thousand people got to Washington, and finally decided that they came from New York over the Pennsylvania Railroad. He said, "I know they did, because I have done it." There is a great deal of that sort of thing in the controversies I have mentioned. The Germans base their opinion entirely on their local experiences, and we run the risk of basing our conclusions upon our local experiences, in the same way. If we can get together and see that there is more than one reaction which will produce a given compound, more than one way in which you can reach a given point, I think we shall get ahead a great deal faster than if we try to adopt one view and force that upon everybody else. That, I think, is all I can say on this very large subject. (Applause.)

AN EXPERIMENT IN CERAMIC EDUCATION

BY HERFORD HOPE, NEW BRIGHTON, PA.

INTRODUCTION—NECESSITY FOR THE SCHOOL

During the writer's experience as foreman of the Mayer China Company, Beaver Falls, Pennsylvania, he has, at various times, come into contact with quite a number of boys and young men who have been really anxious to work their way up to better positions. A few have actually done so, but the majority, for various reasons, but partly because they could not get the instruction they required, have not made much progress, and after some years have settled down to work at the bench for the rest of their lives. For a long time it has seemed that something should be done to help in cases of this kind; but until a little over a year ago, nothing was attempted.

HISTORY OF WORK ALREADY DONE

The incident that brought the matter to a head will also explain the chief motive of the project. In the course of a personal conversation with one of the boys, he told me that he would very much like to go back to school, but was, of course, compelled to stay at work in order to earn his living. I spoke of the opportunities afforded by night schools and correspondence courses, reflecting at the same time that none of these gave instruction in ceramic work, and that in order to advance himself, the boy would soon have to leave the pottery. Obviously, then, at this rate we would be likely to lose the brightest and steadiest boys we had, and why should they not be encouraged to remain with us, at least for a long time, by giving them an education in our own business? The matter appealed to the writer with such urgency that a few weeks later, after notice of the proposed class had been posted in the clay shop and all had had an opportunity to read it, a preliminary meeting was held, and a class of ten started, all but two being potters. An elementary chemistry by Williams which had been used in the local high school was adopted as the textbook, and

the class met twice a week at the writer's home in New Brighton, where a laboratory had been fitted up. The cost of the books, apparatus, etc., is defrayed by weekly dues of twenty-five cents paid by each member to one of their number, who acts as treasurer.

The class was discontinued from May 1st until September 1st; but those who were deficient in arithmetic were given one lesson per week in that subject, and thus were more nearly on an equality with others when the class started again.

On recommencing in September, chemistry was continued on Thursday evenings at my house, the other period being on Saturday afternoons and held in one of the rooms at the pottery. On these Saturday afternoons, we began a very brief outline of geology, leading up to the occurrence of clays and the other raw materials used in pottery bodies, then the methods used in their preparation both in this country and in England, and finally the effect of each ingredient in a normal earthenware or china body, this being shown by each member of the class mixing a body containing different proportions from those of the others. At this point it was intended to proceed with the manufacturing processes from the sliphouse to the glost warehouse; but before beginning, it was apparent that some knowledge of the principles of physics would first be necessary. Physics, therefore, was substituted as the subject for Saturday afternoons, an elementary but well arranged work by Mann and Twiss secured, and study begun.

PLANS FOR THE FUTURE

The above is our present status, the following being what the writer expects to cover in about three or four years more. The chemistry textbook should be finished by December of this year (1913) and the physics, omitting the greater part of the subjects light and sound, not much later. Then for the remainder of that year we expect to cover under Body Preparation: body mixing, wet and dry, blungers, sifters, lawns, electro-magnets, slip-pumps, filter-presses, air and centrifugal pressing, slip kilns, pug mills, kneading machines, hand wedging. Under Shaping Processes: pressing and casting (leaving the subject of alkali additions to slips for the present); handle making and sticking up; jiggering; pressing from steel dies; mouldmaking and modelling;

(these would be gone through rapidly as they are part of the daily work of the potters); preparation of plaster. Then under Drying: natural and artificial drying; stove-rooms, various types; damp closets; ventilation. Under the head of Firing: kilns, updraft, principles of contruction with examination by the class of kilns under repair (drawings to be made of these); practical instruction in firing; fuels, calorific power etc.; gas analysis and draft gauges; cones, their composition and use; electrical and other pyrometers; comparison of analyses of fire clays; sagger bodies; sagger making; fire brick; study of refractories under load conditions. Under Placing: biscuit placing of earthenware, feldspar china and bone china; setters; designing profiles for jigger tools. Synchronous with the above, we will give a continuation of the experiments to show the effect of the various body materials, making all possible combinations of flint, feldspar, china and ball clays, these to be made up, fired and studied; this will also be a study in eutectics. On the manufacturing side will be given the following subjects: down-draft kilns, hard porcelain kilns, continuous kilns, (muffles will be treated of later); efficiency of kilns; heat lost and utilized. This will end the second year.

The subjects included under the head of manufacturing processes for the third year's work are as follows: biscuit brushing, cleaning and scouring machines; biscuit loss, causes and remedies; glaze materials and their preparation; glaze grinding (mixtures to be taken up later); ball mills, pans, etc.; dipping, earthenware and china; weight of glaze; mechanical dipping; drying mangles, etc.; glost placing; sagger washes; stilts and pins; bitstone; glost saggers; cranks, etc.; glost firing; dressing, grinding and polishing glost ware; carborundum blocks, wheels, etc.; glost thirds and loss, causes and remedies; printing, hand and machine; multicolor printing; oils, sizes, etc.; general notes on the preparation of colors (specific details given later); lithographic transfers and their manufacture; enamel kilns, intermittent and continuous, construction and firing; placing.

Carried on synchronously with the above will be the following studies: value of ultimate and rational analysis; ceramic calculations; compounding of earthenware bodies, china bodies with the effect upon them of various fluxes, bone china, hard and soft por-

celain, parian, jasper, stoneware, etc.; stains and decolorizers, effects of iron on clays; effect of fine division of materials on vitrification and other points; elutriation and surface factor; effect of the addition of alkalies to slips; measurement of vitrification, porosity, specific gravity, hardness, translucency, etc. The foregoing should be covered by the end of the third year.

The fourth year's work will comprize the study of the following: glazes and glasses, the various types, their range of composition and use; raw lead glazes; salt glazes; earthenware and china glazes; frits; frit kiln construction; composition of lining with reference to composition of frit to be melted; hard porcelain glazes; leadless glazes for earthenware; colored, mat and crystalline glazes; effect on various colors of glazes of various compositions; defects of glazes and their remedies; colors, underglaze, their preparation; blues, greens, browns, blacks, greys, pinks, and purples, yellows, etc.; underglaze fluxes; overglaze colors and fluxes; preparation of gold colors; lusters, raised paste, etc.; gold printing; general review of pottery manufacture; designing and arranging a pottery; outline of other ceramic manufactures.

CONCLUSIONS

The writer does not imagine for a moment that he has included all the subjects that should be taught in order to give a thorough knowledge of pottery manufacture; but he does believe that if the foregoing schedule is covered with a fair degree of thoroughness and if the class will see the various processes for themselves as they are given the opportunity to do, they should have a fair general idea of the business at the end of four or five years.

Of course the advancement of any individual rests chiefly with himself, and it is my special desire to impress on the class that no matter what their opportunity, hard work and study are absolutely essential. Furthermore, very small measure of success will be attained in any executive position unless the individual has a certain tact and skill in handling his employes and a thorough knowledge of the class of labor with which he is dealing; and the possession or lack of this faculty soon becomes apparent at the bench, for almost all the potters over twenty years of age, and a good many younger, have one or more younger boys working for them,

and the manner in which they manage these boys furnishes a true index of their future success in handling men. Much more could be said on the methods employed in teaching this experimental class; but as the teacher is as much of an experiment as the class, he does not think his opinions would carry weight at this time.

In conclusion the writer wishes to acknowledge with thanks the kind help given by Prof. A. V. Bleininger of the U. S. Bureau of Standards and Arthur Heath, Esq., Instructor in the Pottery Schools of North Staffordshire, England, in preparing the schedule outlined above.

DISCUSSION

Prof. Orton: I have been interested in Mr. Hope's paper. The point upon which he is having difficulty strikes me as a practical difficulty for almost any similar case. In any one manufacturing concern, it might not be necessary to start a new class every year, but in any large pottery community, there would certainly be an oncoming class every year that should receive assistance, and it seems hard to force a growing boy to wait longer than a year for an opportunity to get in to a profitable course of study at the beginning. The difficulty of getting into a course at any other place than the beginning is more or less like getting a link into a continuous chain.

Mr. Hope's work reminds me of the work that is being done in the University of Cincinnati, where they are trying out, in a rather large way, an experiment in co-operative engineering education. A group of students work about one half time in the shop, and one half time in the University. The co-operating shops are mostly machine shops, located in Cincinnati and vicinity, and they contract to take on a certain number of these student apprentices, and to provide work for them for certain portions of each week. The boys work in the shop on commercial work, as I understand it. An instructor of the University keeps in reasonably close contact with what each boy is doing in the shop, so that their work will, to some extent, be supplemented by the training work that they get at school. They get credit for the work they do at the shop as a part of their course. The significance of the exper-

iment is perhaps somewhat indicated by the popularity of it; the waiting list is said to be something like ten times the total possible registration in the course; that means that the youth of Cincinnati are so impressed with this mode of education, that if they could, they would fill up ten schools at once. The experiment has been in process for some five or six years now—four or five years at least. It has not been largely tried elsewhere, though I understand the University of Pittsburgh is beginning a similar system.

There is a pretty general trend, I may say, towards vocational work in schools, and making the school training give some direct preparation for a business. It seems to be in the air. Congress has been considering within the past few days an enormous appropriation, estimated to run from thirteen to sixteen million dollars, to carry vocational training into the public school systems of the various states, or to provide governmental co-operation for that purpose, making it necessary for the states to do their part, of course, in maintaining such a system. The part of the state is much larger than the part of the government, but in order to get the government aid, the state must make its expenditure. It seems that we shall probably all of us live to see the day when vocational training will have its well accepted place in the educational scheme, and these sporadic efforts which have been made thus far, such as Mr. Hope has described, and which I think Mr. Greener describes, and which I have attempted to describe, are just feeling the situation out. We must prepare our minds for rather radical innovations in our educational system. The old principles of education, which have stood for so long, which make no recognition of the use of one's hands, I think are bound to be radically supplemented; they have been radically supplemented already, and probably we have barely begun the process of revision.

Mr. Lovejoy: Professor Orton might have drawn an illustration, I think, closer at home, but of course not in as high work as the University. Our trade school at Columbus, Ohio, is working identically along the line mentioned by him and Professor Purdy, and it is part of our public school system. The first year is given entirely to school work. After the first year, if they carry the first year's work creditably, which is always an inducement to

them, the students are placed in factories about the city, working a week in the factory and the alternate week in the school. Two boys are sent out for each place so that there is always a continuous workman in the factory. One will work one week and go to school the next, and alternate with the second boy. The school has been in operation now several years in the city and I believe is doing good work. I think, as Professor Orton says, that we are coming to that very thing in all our school work. It is my impression that McGill University of Montreal, Province of Quebec, requires from every engineer—at least in some departments it is true—one year's practical work before a degree is granted, in fact before the student is permitted to take the senior year's work.

Mr. Cronquist: I don't know whether it is of interest for a person to hear about the manner in which we, in Sweden, teach the foreman. I think it was twelve years ago that the foremen themselves in the brick yards in Sweden felt that they did not know enough about the brick business; and they started, together with the manufacturers, a school for foremen in brick yards—for the foremen themselves, for burners and for the foremen's boys. They did not make an ordinary school; but they built a brick yard and produced in this yard about half a million bricks and tiles. In the winter time the boys received instruction there, and in the summer time they can learn how to run a plant. They have, however, at first, to have at least two years practice and of that one year burning before they can enter the school. That is perhaps a parallel that you can use here in the pottery business.

Dr. Boyd: In connection with the education of the members of any manufacturing line, I have found in one large institution in particular that I was connected with that they would educate the men very satisfactorily by placing within the grasp of each individual an opportunity of attending a meeting once a week and having these meetings addressed by the heads of different departments. Now, it occurs to me that this point might be well taken here, that manufacturers in the clay working industries should give their employes an opportunity of meeting and being addressed by the heads of the different departments. You will find that the man in the packing department is very much interested in what is going on in some other part of the factory; and you

may have a man in the back of the factory who is very much interested or wants to be interested in what is going on in some other part. By having these meetings and having the heads of the different departments explain the business, you are gradually educating your men to be familiar with the whole line. I have seen this tried in a factory where they employed ten thousand people, and it worked very effectively and has brought to the front dozens of young men who had never been heard of before.

Mr. Purdy: This subject is one of great importance. The course described by Professor Orton as being carried on in Cincinnati is bringing the "high brows" to the bench. We want a course that will bring the bench a little way at least toward the high brows; in other words, we need a trade school course, one that will fit the factory boys. It is very important that the university man shall know what it is to run a machine. He cannot be an engineer if he cannot run a planer and run it on fine jobs; but it is highly important that in some way we encourage the boys in the factory. At the Norton Company, Worcester, we are contemplating this very step and are trying to make an arrangement with the Trade School of that city to take the preliminary classes, i.e., the elementary work described by Mr. Hope, adapting it to the needs of our business, and then we to go into that same school and teach the ceramic problems. Our aim is not to teach ceramics so much, because we do not care about that job, as it is to interest these boys. It reverts back to the old problem how much you will let the boys into the so-called trade secrets of the factory. We can not make machines out of human beings any longer. We have become so specialized, that they do not know very much when they confine their knowedge to just one particular part of the work; so we, to interest them, had thought that perhaps a general course of ceramics would take them out of their little part of the bench into the factory at large—mentally, of course; and we do not expect, in that, to disclose valuable trade secrets, for we find that we can teach very broad principles about bodies and glazes, even the bodies and the glazes used in the factory, without giving specific data.

We think it is very important that we should do this, and it is the same sort of disclosure of facts that we, in the Ceramic So-

ciety, ask. Manufacturers who are coming continually to listen to these papers, know there are things being said that are of importance to the work of each or he would not be coming. These same persons could recite experiences which would not be a disclosure of what they are using; and in the same sense we can teach, in the factory, very definite problems, as Mr. Hope expects to do, in the Mayer Pottery Company, without disclosing to these young men all the secrets that would make him a successful potter; although in the end, the object would be of course to prepare him so that, if he had it in him he could be a successful potter. We hope to do the same thing. It is a trade school idea in the factory, and I think we all ought to encourage that.

Mr. Hastings: I will say that in Hartford, the metal working trades, of which that is quite a center, have gotten together and sent the boys, about forty at present, to the High School, which is well equipped in that line, for two afternoons a week. The boys draw pay just the same as if they were working in the factory. Of course it is quite a new experiment; but it is working out splendidly. The boys are made to go to school; the manufacturers think it is worth while.

THE EFFECT OF OVERBURNING UPON THE STRUCTURE OF CLAYS[1]

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INTRODUCTION

The formation of vesicular structure in clays during burning is a well known phenomenon, and repeatedly in the *Transactions* attention has been called to the presence of pore space into which water cannot penetrate and which, therefore, finds no expression in the absorption tests as commonly practiced. Purdy especially has brought out this point in several of his investigations, although actual determinations have been reported only in one paper,[2] where a fire clay was made the subject of study.

The tendency of a clay to form vesicular pore spaces is as much a characteristic property as the decrease in initial porosity. The magnitude of this formation of "bleb" structure is necessarily of considerable influence upon the properties of the burned material, especially in the case of paving brick, electrical porcelain and dinner ware, glass pots, etc., since it cannot be denied that it is more or less deleterious in every case. On the other hand, we must recognize the fact that the conditions of burning have much to do with causing vesicular structure, of which incomplete oxidation and too rapid burning or over heating are the most prominent. But, even though all precautions are taken, a certain amount of gaseous matter is given off by every clay, resulting in more or less permanent enclosed pore space. The gases evolved may be of various origin and may consist of air contained within the clay; sulphur di and tri oxide, steam, carbon dioxide or monoxide, oxygen and even hydro-carbons absorbed during the burning. Both the inherent structure of the clay, as well as that imparted to it in molding are important factors. The effect of the artificial structure of clays is illustrated by the case of two paving-brick shales with which the writers are acquainted. In both cases inferior results were obtained as long as the materials were put

[1] By permission of the Director, Bureau of Standards.

[2] *Trans. Am. Ceram. Soc.*, vol. 13, p. 603.

through a fine screen. As soon as coarser screens were adopted, the quality of the burned ware was improved decidedly as was shown by the more satisfactory rattler results. A considerable number of clays, especially certain surface and No. 2 fire clays, cannot be burned to the non-absorbent state of vitrification, owing to the formation of vesicular structure which takes place long before the porosity approaches non-absorption. This peculiar property of clays therefore should receive careful consideration. Starting from this extreme, we find clays which reach the state of non-absorption, but which at this point develop the enclosed pore space very rapidly. On the other hand, certain materials are less sensitive to temperature increase and show no marked change in this respect. These obviously are the most desirable clays. Practically no densely burnt clay mass is without vesicular structure. Open grained bodies, like fire brick, however, may be said to be free from enclosed pore space.

EXPERIMENTAL PART

Owing to the importance of this topic it was considered advisable to do some work along these lines, consisting in the determination of the total and enclosed pore space of clays burned to several temperatures, starting from the point at which maturity has been reached. Six clays were used in this work, as follows: No. 1, surface clay, weathered shale, Cleveland, Ohio; No. 2, surface clay, glacial, Curtice, Ohio; No. 3, shale, Galesburg, Illinois; No. 4, shale Cleveland, Ohio; No. 5, No. 2 fire clay, Union Furnace, Ohio; No. 6, No. 2 fire clay, Kittanning, Pennsylvania.

Each batch of these clays was pugged to uniform consistency, and all the specimens were molded from the same lump, rendered as homogeneous as possible. The molding was done in brass molds, and the trials were practically cubes, weighing about 130 grams in the burnt state. The drying was carried on slowly at room temperature.

In the burning a constant rate of temperature increase of 20°C. per hour was maintained during all the burns. Due to the use of natural gas, this was easily possible, and the heating curve proposed was followed very closely. The temperature measurements were made by means of a thermocouple and a Siemens-Halske re-

cording milli-voltmeter. Part of the time a second couple was inserted through the back of the kiln in order to check the uniformity of the heat distribution. Cones were placed in each burn. The cold junctions were kept in glass tubes cooled in ice water. At each of the selected temperature three trial pieces were drawn for the purpose of checking the results. Upon drawing, the sets of specimens were cooled in a pot furnace previously fired to a red heat.

The trial pieces were then weighed, saturated with water, in vacuo, followed by the usual determination of the suspended and wet weights. An average sample of the brickettes was then obtained, which was pulverized for the estimation of the true specific gravity by means of the pycnometer.

From these values the percent of apparent porosity was calculated from the relation $100\ (W\text{-}D)\text{–}(D\text{-}S_1)$. The pore space is expressed here in terms of the true clay volume, viz., dry weight divided by the true density. Similarly the percent volume of the enclosed pores space was reckoned from the formula:

$$\frac{100\left(\frac{D}{S_2} - \frac{D}{S_1}\right)}{\frac{D}{S_1}} = 100\left(\frac{S_1}{S_2} - 1\right).$$

In these expressions:

D = dry weight of specimen.
W = wet weight.
S_1 = true specific gravity.
S_2 = apparent specific gravity of saturated piece.

The total porosity, of course, represents the apparent pore volume plus the volume of the enclosed pore space, all of the values being expressed in terms of the true clay volume. It is quite evident that the apparent specific gravity of the piece equals the true specific gravity only under two conditions, viz., when there are no enclosed pore spaces or when all of the latter are open and may be occupied by water. The former case is impossible; the latter is frequently realized with open grained fire rick and similar materials.

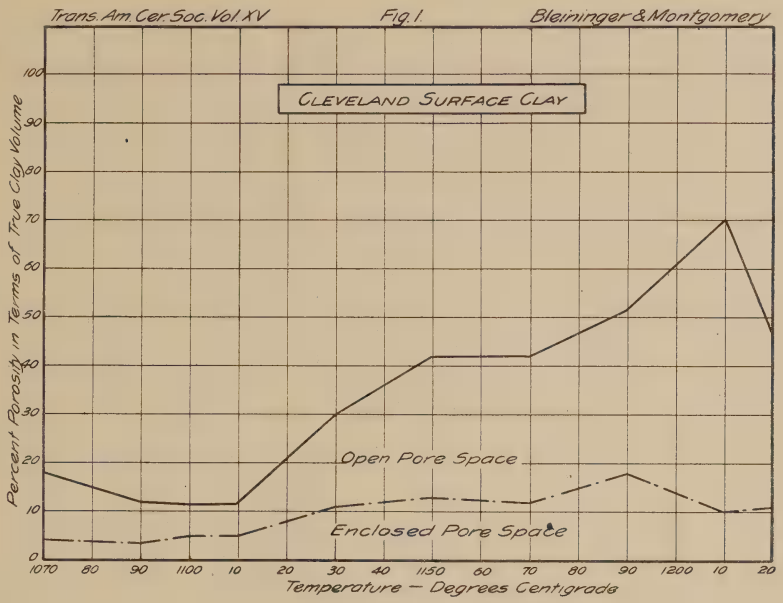
In this investigation overburning was studied rather than normal conditions in order to bring out the readiness, varying for different clays, with which they become spongy and to determine if possible how important a factor the enclosed pore space is in bringing about the swelling. At the same time it seemed desirable to follow the changes in density upon heating the clays beyond the stages of maximum strength and dense vitrification.

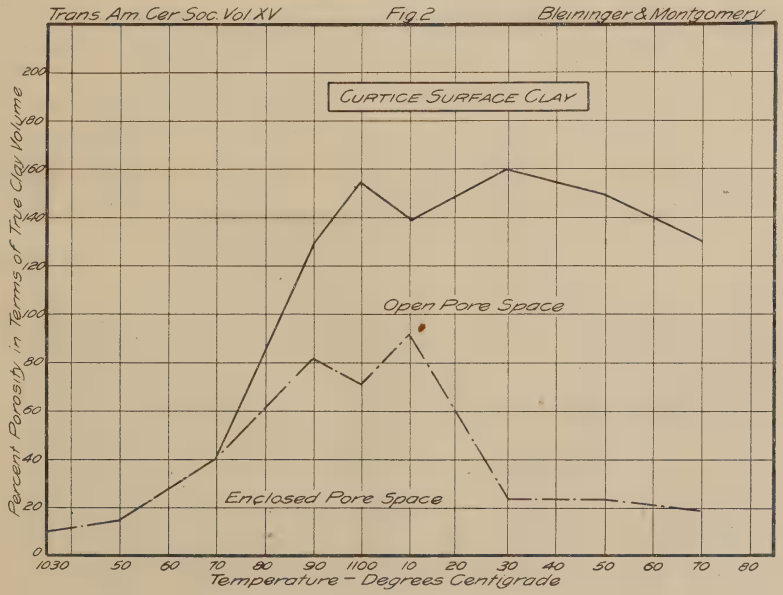
The results of this work are compiled in Tables 1 to 6. Attention might be called at this point to the regularity with which the cones went down in the different burns, which is due to the fact that the same rate of firing was maintained throughout. This emphasizes the importance of associating the softening points of cones with definite rates of heating. It should become common practice to compare cone temperatures on the basis of time-temperature curves.

In Figures 1 to 6 inclusive, the results of the porosity determinations are shown graphically.

Cleveland Surface Clay (Fig. 1). In considering results of this kind it is well to remember that the accidental factors entering into this question are quite prominent. The initial structure of the clay, the method of molding, the rate of heating, the character of the kiln atmosphere, shorter or longer periods of over-firing, all influence the porosity conditions. In the present case we have minimum absorption, 2.4 percent, and porosity at 1110° followed by a rather sudden increase in porosity. The clay does not become densely vitrified at any temperature. Overburning begins within one cone of minimum absorption with decided development of vesicular structure. Such facts as these clearly show the impossibility of using such clays for the manufacture of paving brick. The enclosed pore space also increases, though not as markedly as might be expected from the development of the porosity.

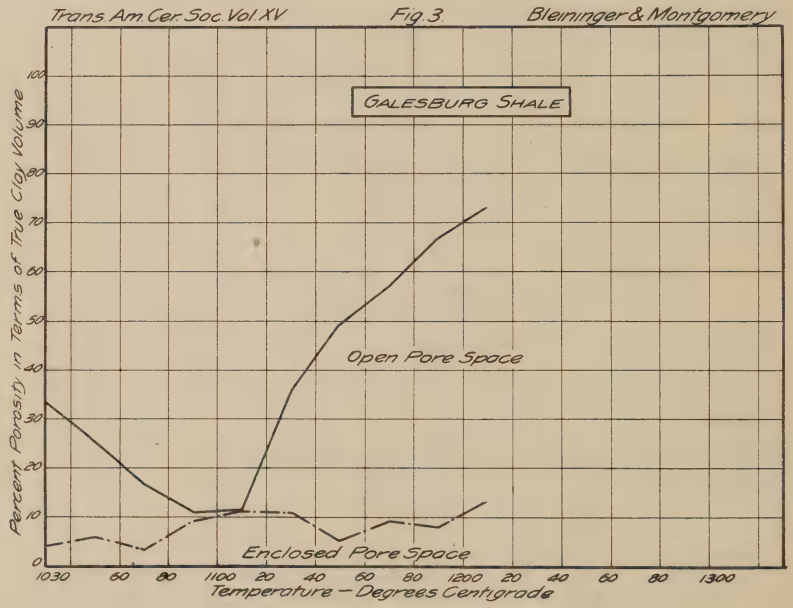
Curtice Surface Clay (Fig. 2). The conditions are very similar to those in the preceding case, with the exception that the vesicular structure develops very strongly and then subsides decidedly as the gases escape. In time, of course still higher temperatures would cause more or less complete expulsion of the gases and reduction of total porosity so that finally we would have a glass


Trans. Am. Cer. Soc. Vol. XV
Fig. 1
Bleininger & Montgomery
Cleveland Surface Clay
Open Pore Space
Enclosed Pore Space
Percent Porosity in Terms of True Clay Volume
Temperature — Degrees Centigrade
0
10
20
30
40
50
60
70
80
90
100
1070 80 90 1100 10 20 30 40 1150 60 70 80 90 1200 10 20


Trans. Am. Cer. Soc. Vol. XV
Fig. 2
Bleininger & Montgomery
Curtice Surface Clay
Open Pore Space
Enclosed Pore Space
Percent Porosity in Terms of True Clay Volume
Temperature — Degrees Centigrade
0
20
40
60
80
100
120
140
160
180
200
1030 50 60 70 80 90 1100 10 20 30 40 50 60 70 80

of no apparent porosity but still possessed of a system of enclosed pores.

Galesburg Shale (**Fig. 3**). This material reaches minimum absorption at between 1090° and 1110°, 0.5 per cent at 1090° and zero at 1110°. At these points the open pore space is negligible in volume, but the vesicular structure has developed rapidly, beginning with 1070°C. For best results, therefore, the best burning temperature should not exceed 1090°. The margin of safety

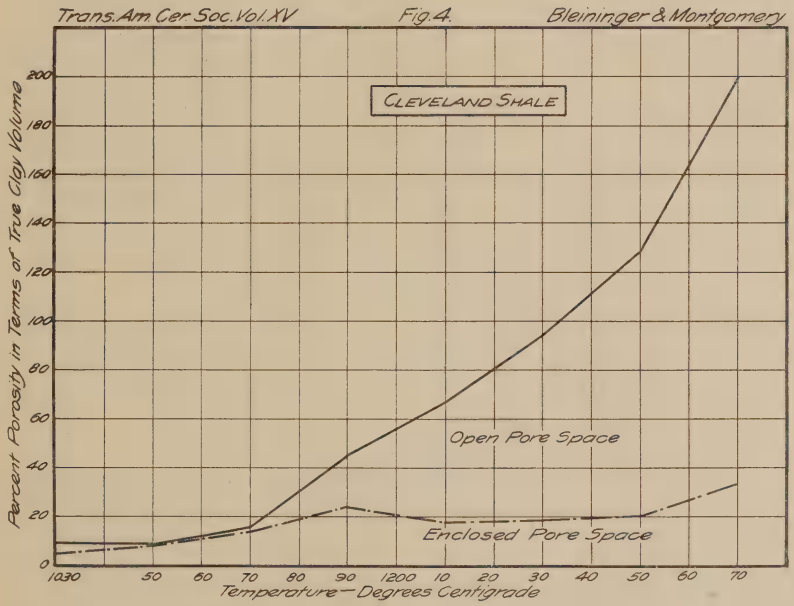


of this material has clearly been shown to be small, as is typical of many Illinois shales. The importance of following the development of the vesicular structure is thus clearly indicated since the ordinary porosity curve would fail to bring out the weakening influence of the factor in question. It is noted that the enclosed pore space diminishes again, though the total porosity is increased rapidly.

Cleveland Shale (**Fig. 4**). This material differs markedly from the preceding one inasmuch as the range of non-absorption is

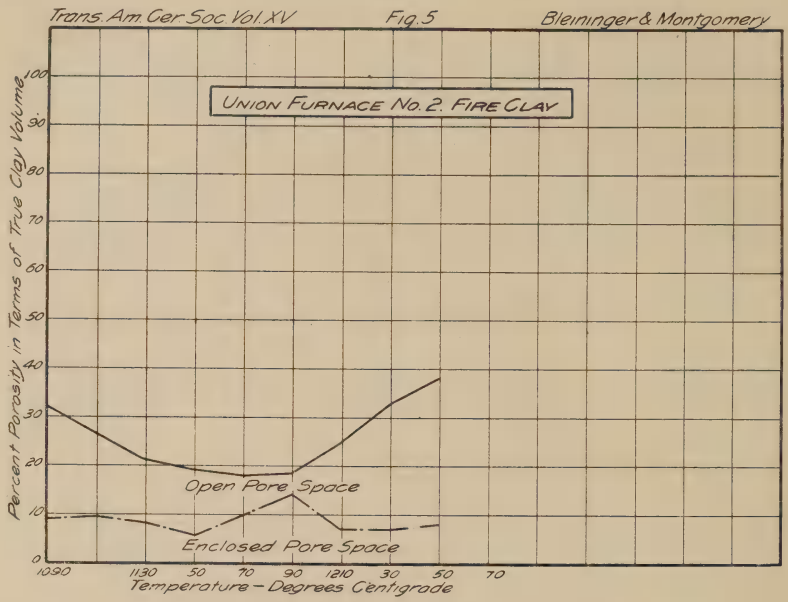
very much longer. It is noted that the pore space represents practically altogether enclosed "bleb" structure up to 1070°. From this point on the total porosity increases quite rapidly and the enclosed pore space more slowly.

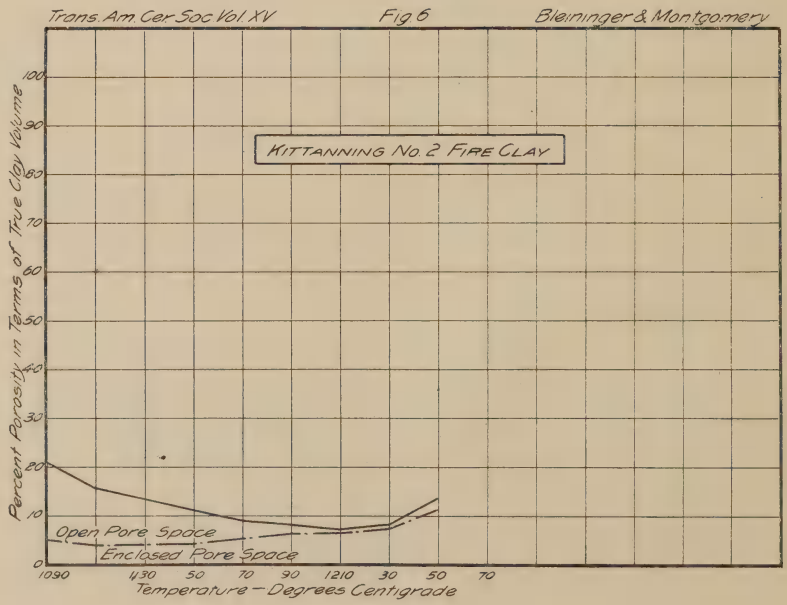
Union Furnace No. 2 Fire Clay (Fig. 5). This clay shows a gradually decreasing total porosity with diminishing absorption, interrupted between 1130° and 1170° by the increased vesicular structure. The lowest absorption is 2.14 percent (in terms of the



dry weight) and is reached at 1190°. From this point on the total porosity gains rapidly although at the same time there is a marked decrease in enclosed pore space. The diagram shows clearly that this clay cannot be vitrified to a dense structure at commercial temperatures and hence would not be suitable for the manufacture of stoneware or similar products.

Kittanning No. 2 Fire Clay (Fig. 6). This material shows a markedly different behavior from the preceding clay of the same type. Starting with an absorption of 6.28 percent at 1090°, it


Trans. Am. Cer. Soc. Vol. XV
Fig. 5
Bleininger & Montgomery
UNION FURNACE No. 2. FIRE CLAY
Percent Porosity in Terms of True Clay Volume
100
90
80
70
60
50
40
30
20
10
0
Open Pore Space
Enclosed Pore Space
1090
1130
50
70
90
1210
30
50
70
Temperature – Degrees Centigrade


Trans. Am. Cer. Soc. Vol. XV
Fig. 6
Bleininger & Montgomery
KITTANNING No. 2 FIRE CLAY
Percent Porosity in Terms of True Clay Volume
100
90
80
70
60
50
40
30
20
10
0
Open Pore Space
Enclosed Pore Space
1090
1130
50
70
90
1210
30
50
70
Temperature – Degrees Centigrade

reaches practically complete non-absorption, which condition is retained up to 1250°. At 1250° vesicular structure is developed, although the open pore space is not increased in volume. The diagram shows very strikingly the excellent qualities of this clay and its suitability for all products requiring dense structure and safe firing behavior.

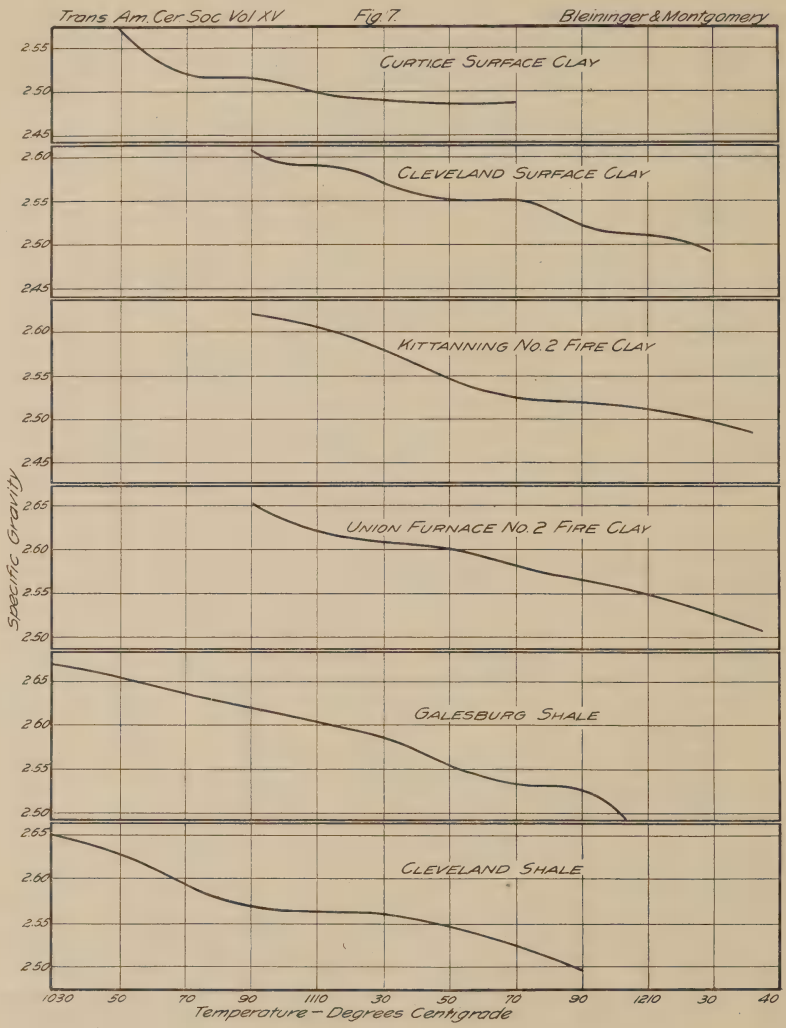
Specific Gravity. The increase in the specific volume of these clays is shown by the tables as well as by the curves of figure 7. It is at once observed that in no case constant conditions have been reached, but that the density continues to decrease at a steady rate. This is further evidence tending to show that we are dealing here with a state far from equilibrium, which is reached only when complete fusion has been brought about. It is interesting to note the drop on the specific gravities which are as follows:

CLAY	MAXIMUM DENSITY	MINIMUM DENSITY	DIFFERENCE
Cleveland surface clay	2.63	2.49	0.140
Curtice surface clay	2.61	2.485	0.125
Galesburg shale	2.67	2.495	0.175
Cleveland shale	2.65	2.500	0.150
Union Furnace No. 2 fire clay	2.655	2.505	0.150
Kittanning No. 2 fire clay	2.62	2.48	0.140

SUMMARY

In the testing of clays, the question of development of vesicular structure should receive careful attention and should be included in every complete report. Owing to the fact that the conditions of firing and other factors enter into the formation of enclosed pore space, thorough sampling and carefully conducted burning is essential.

A definite rate of firing after the complete oxidation of the material should be maintained. The study of vesicular structure is more important in the case of materials where sound vitrification is required, as in the case of sewer pipe, paving brick, stoneware, electrical porcelain, etc., than for open grained products. It is advisable to express all volume relations in terms of the true clay volume.



The continuous decrease in the specific gravity of the overburned clays show that molecular changes are still going on and that equilibrium is by no means reached at the stage of complete vitrification.

TABLE I—CLAY NO. 1, CLEVELAND SURFACE CLAY

TEMPERATURE	CONE	TRIAL NUMBER	WET WEIGHT	DRY WEIGHT	SUSPENDED WEIGHT	APPARENT SPECIFIC GRAVITY	AVERAGE APPARENT SPECIFIC GRAVITY	TRUE SPECIFIC GRAVITY	APPARENT POROSITY	AVERAGE APPARENT POROSITY	TRUE POROSITY OF SEALED PORES	TRUE TOTAL POROSITY
°C.									percent	percent	percent	percent
1070	1	1	148.4	141.3	85.6	2.54			13.2			
		2	144.2	137.2	83.0	2.53			13.5			
		3	143.3	136.3	82.4	2.53	2.53	2.63	13.5	13.4	4.1	17.5
1090	2	1	138.0	132.9	80.6	2.54			10.0			
		2	145.0	140.0	84.7	2.53			9.3			
		3	138.1	133.8	80.6	2.52	2.53	2.61	8.4	9.2	3.1	12.3
1100	3	1	139.7	136.1	80.9	2.47			6.8			
		2	140.6	137.6	81.2	2.44			5.7			
		3	142.3	139.0	82.4	2.46	2.45	2.59	6.1	6.2	5.4	11.6
1120	5	No trials drawn										
1130	6	1	149.4	139.7	78.0	2.26			17.7			
		2	145.0	136.2	77.6	2.32			16.6			
		3	148.8	136.2	77.8	2.33	2.31	2.57	23.7	19.3	10.7	30.0
1150	7	1	149.7	135.0	72.8	2.17			27.7			
		2	149.8	135.3	73.0	2.17			27.0			
		3	152.3	135.9	75.5	2.25	2.20	2.55	30.7	28.4	13.3	41.7
1170	8	1	153.8	136.9	77.6	2.31			31.4			
		2	148.4	133.2	74.6	2.27			29.1			
		3	157.3	141.3	78.9	2.26	2.28	2.55	29.0	29.8	12.4	42.2
1190	9	1	158.0	142.3	75.4	2.13			26.0			
		2	152.2	134.0	71.0	2.13			34.3			
		3	160.3	138.1	73.3	2.13	2.13	2.52	40.0	33.4	18.1	51.5
1210	10	1	167.0	140.2	75.6	2.17			48.0			
		2	171.5	141.7	77.0	2.19	2.18	2.51	53.2	50.6	14.7	65.3
1230		1	123.4	110.4	59.4	2.16			30.0			
		2	177.6	156.6	82.6	2.12	2.14	2.49	33.3	31.6	15.3	46.9

TABLE II—CLAY NO. 2, CURTICE SURFACE CLAY

TEMPERATURE	CONE	TRIAL NUMBER	WET WEIGHT	DRY WEIGHT	SUSPENDED WEIGHT	APPARENT SPECIFIC GRAVITY	AVERAGE APPARENT SPECIFIC GRAVITY	TRUE SPECIFIC GRAVITY	APPARENT POROSITY	AVERAGE APPARENT POROSITY	TRUE POROSITY OF SEALED PORES	TRUE TOTAL POROSITY
°C.									percent	percent	percent	percent
1030	03	1	114.1	113.8	66.5	2.41			0.7			
		2	108.1	107.8	63.1	2.41	2.41	2.61	0.6	0.7	8.2	8.9
		3										
1050	02	1	113.1	113.0	63.8	2.29			0.0			
		2	109.7	109.6	60.6	2.24	2.27	2.57	0.0	0.0	15.0	15.0
1060	01	No trials drawn										
1070	1	1	119.8	119.8	52.7	1.79			0.0			
		2	115.0	115.0	50.7	1.79			0.0			
		3	117.2	117.2	54.3	1.86	1.81	2.52	0.0	0.0	41.0	41.0
1090	2	1	143.8	116.2	35.5	1.44			60.0			
		2	126.2	110.0	28.0	1.34			37.0			
		3	135.5	114.8	31.5	1.38	1.38	2.515	45.4	47.4	82.4	129.8
1100	3	1	155.8	115.8	37.8	1.48			87.0			
		2	152.6	116.0	37.3	1.47			80.0			
		3	149.6	109.9	37.3		1.48	2.51		83.5	71.3	154.8
1110	4	1	133.1	109.6	29.3	1.36			53.4			
		2	127.4	108.5	24.1	1.30			43.6			
		3	127.0	108.3	20.4	1.23	1.30	2.495	44.0	47.0	92.0	139.0
1120	5	No trials drawn										
1130	6	1	163.4	106.3	53.8	2.02			134.0			
		2	167.0	107.2	54.1	2.02			139.0			
		3	174.2	115.4	54.7		2.02	2.49		136.0	23.4	159.4
1150	7	1	154.8	102.7	51.9	2.02			126.0			
		2	140.7	94.0	46.8	2.00			123.0			
		3	165.6	108.8	54.3	2.00	2.00	2.485	130.0	126.3	23.0	149.3
1170	8	1	138.2	95.2	49.6	2.09			112.2			
		2	127.2	87.7	46.0	2.10			112.0			
		3	116.5	80.6	42.6	2.12	2.10	2.485	111.1	112.0	18.4	130.4

TABLE III—CLAY NO. 3, GALESBURG, ILL., SHALE

TEMPERATURE	CONE	TRIAL NUMBER	WET WEIGHT	DRY WEIGHT	SUSTAINED WEIGHT	APPARENT SPECIFIC GRAVITY	AVERAGE APPARENT SPECIFIC GRAVITY	TRUE SPECIFIC GRAVITY	APPARENT POROSITY	AVERAGE APPARENT POROSITY	TRUE POROSITY OF SEALED PORES	TRUE TOTAL POROSITY
°C.									*percent*	*percent*	*percent*	*percent*
1030	03	1	143.7	129.3	79.0	2.57			30.0			
		2	139.2	126.1	76.7	2.56	2.56	2.67	28.0	29.0	4.2	33.2
1050	02	1	140.4	131.4	78.7	2.50			18.2			
		2	141.6	131.5	78.9	2.50	2.50	2.655	20.4	19.3	6.2	25.5
1070	01	1	132.4	125.6	76.9	2.57			14.3			
	&											
	1	2	138.4	131.1	80.0	2.56			14.6			
		3	134.4	127.8	78.3	2.58	2.57	2.635	13.4	14.1	2.5	16.6
1090	2	1	128.2	127.5	73.6	2.36			1.5			
	&											
	3	2	125.0	124.1	72.3	2.40			1.9			
		3	127.1	125.8	73.4	2.40	2.40	2.625	1.7	1.7	9.2	10.9
1110	4	1	127.7	127.5	73.5	2.36			.4			
		2	128.9	128.8	74.0	2.35			.2			
		3	128.9	128.6	74.2	2.35	2.35	2.605	.6	.4	11.3	11.7
1130	5	1	134.5	123.5	70.2	2.32			23.0			
	&											
	6	2	137.1	125.2	71.9	2.34			24.6			
		3	148.1	133.6	77.5	2.38	2.35	2.59	28.1	25.2	10.8	36.0
1150	7	1	150.9	129.0	75.9	2.43			43.3			
		2	149.1	127.2	74.4	2.41			43.8			
		3	143.5	122.6	71.7	2.41	2.41	2.555	43.7	43.6	6.0	49.6
1170	8	1	155.4	129.9	73.9	2.32			49.8			
		2	151.8	127.2	72.7	2.33			49.1			
		3	150.2	126.9	71.8	2.30	2.32	2.535	46.6	48.5	8.7	57.2
1190	9	1	152.5	124.5	69.8	2.28			56.9			
		2	155.7	125.7	72.1	2.34			60.3			
		3	157.7	127.3	73.0	2.34	2.32	2.53	60.4	59.2	8.1	67.3
1210	10	1	179.4	143.7	78.9	2.22			62.0			
		2	131.9	106.5	57.9	2.20			60.0			
		3	108.7	88.9	47.0	2.12	2.20	2.495	55.5	59.2	13.3	72.5

TABLE IV—CLAY NO. 4, CLEVELAND SHALE

TEMPERATURE	CONE	TRIAL NUMBER	WET WEIGHT	DRY WEIGHT	SUSPENDED WEIGHT	APPARENT SPECIFIC GRAVITY	AVERAGE APPARENT SPECIFIC GRAVITY S_2	TRUE SPECIFIC GRAVITY S_1	APPARENT POROSITY	AVERAGE APPARENT POROSITY	TRUE POROSITY OF SEALED PORES	TRUE TOTAL POROSITY
°C.									*percent*	*percent*	*percent*	*percent*
1030	03	1	131.7	130.4	78.4	2.51			3.2			
		2	131.6	130.0	77.9	2.51	2.51	2.65	3.3	3.3	5.7	9.0
1050	02	1	128.6	128.5	75.4	2.42			0.0			
		2	135.2	135.1	79.3	2.42	2.42	2.63	0.0	0.0	8.7	.8.7
1070	01	1	134.8	134.2	75.4	2.28			1.1			
	&											
	1	2	127.9	126.9	70.7	2.26			2.0			
		3	126.9	126.3	71.7	2.30	2.28	2.595	1.2	1.4	14.1	15.5
1090	2	1										
	&											
	3	2	149.4	138.7	70.8	2.04			20.0			
		3	135.8	124.6	64.2	2.06	2.05	2.57	23.0	21.5	24.0	45.5
1110	4	1	159.0	133.7	73.6	2.22			48.5			
		2	133.6	111.3	62.1	2.26			51.3			
		3	157.0	131.6	73.1	2.20	2.23	2.565	49.5	49.8	17.0	66.8
1130	5	1	171.6	130.7	71.3	2.20			80.4			
	&											
	6	2	168.7	131.3	72.0	2.21			73.3			
		3	176.7	137.3	74.0	2.17	2.20	2.56	73.5	75.7	18.0	93.7
1150	7	1	194.5	136.9	72.8	2.13			107.2			
		2	194.5	134.7	72.1	2.15			111.0			
		3	188.0	132.7	69.2	2.10	2.13	2.55	106.3	108.1	20.0	128.1
1170	8	1	220.2	132.7	63.0	1.90			167.0			
		2	210.8	127.2	61.3	1.92			166.2			
		3	179.6	109.1	49.6	1.83	1.90	2.53	163.6	165.6	33.2	198.8
1190	9	1	252.3	132.5	52.6	1.66			226.4			
		2	247.2	130.7	51.5	1.65			222.7			
		3	248.6	132.6	53.5	1.67	1.66	2.50	220.0	223.0	51.7	274.7

TABLE V—CLAY NO. 5, UNION FURNACE NO. 2 FIRE CLAY

TEMPERATURE	CONE	TRIAL NUMBER	WET WEIGHT	DRY WEIGHT	SUSTAINED WEIGHT	APPARENT SPECIFIC GRAVITY	AVERAGE APPARENT SPECIFIC GRAVITY S_2	TRUE SPECIFIC GRAVITY S_1	APPARENT POROSITY	AVERAGE APPARENT POROSITY	TRUE POROSITY OF SEALED PORES	TRUE TOTAL POROSITY
°C.									*percent*	*percent*	*percent*	*percent*
1090	3	1	147.1	135.0	79.8	2.44			23.8			
		2	142.7	131.9	77.6	2.43			22.0			
		3	146.7	133.9	79.8	2.47	2.45	2.655	25.4	23.7	8.8	32.5
1110	4 & 5	1	142.4	132.3	78.9	2.47			20.0			
		2	148.8	140.3	81.6	2.40			16.0			
		3	144.6	136.4	79.2	2.40	2.42	2.62	16.0	17.3	9.3	26.6
1130	6	1	136.6	130.3	75.8	2.40			12.6			
		2	142.9	136.5	78.9	2.39			12.2			
		3	142.0	136.0	78.5	2.37	2.39	2.61	12.0	12.3	9.1	21.4
1150	7	1	134.2	127.5	75.3	2.44			14.0			
		2	139.8	133.1	79.0	2.46			13.0			
		3	143.6	136.7	81.1	2.46	2.45	2.60	13.1	13.3	5.6	18.9
1170	8	1	144.0	137.6	81.6	2.46			12.0			
		2	134.5	131.5	74.8	2.32			6.0			
		3	142.2	139.1	79.5	2.34	2.37	2.58	6.0	8.0	10.0	18.0
1190	9	1	133.7	130.9	74.0	2.30			6.0			
		2	129.7	127.7	71.2	2.26			4.0			
		3	140.0	138.1	76.9	2.26	2.27	2.57	3.7	4.6	14.0	18.6
1210	10	1	147.8	137.5	80.3	2.40			20.0			
		2	139.4	130.6	76.0	2.39			17.0			
		3	139.0	131.2	75.4	2.35	2.38	2.55	15.3	17.4	7.4	24.8
1230	11	1	143.1	130.3	75.6	2.38			24.8			
		2	149.4	134.7	78.3	2.38			27.6			
		3	151.1	137.0	79.2	2.37	2.38	2.53	26.1	26.1	7.0	33.1
1250	12	1	154.2	137.9	79.5	2.36			30.0			
		2	149.7	134.6	77.6	2.31			30.0			
		3	145.1	130.5	75.2	2.31	2.33	2.505	28.1	29.3	8.4	37.7

TABLE VI—CLAY NO. 6, KITTANNING NO. 2 FIRE CLAY

TEMPERATURE	CONE	TRIAL NUMBER	WET WEIGHT	DRY WEIGHT	SUSTAINED WEIGHT	APPARENT SPECIFIC GRAVITY	AVERAGE APPARENT SPECIFIC GRAVITY S_2	TRUE SPECIFIC GRAVITY S_1	APPARENT POROSITY	AVERAGE APPARENT POROSITY	TRUE POROSITY OF SEALED PORES	TRUE TOTAL POROSITY
°C.									*percent*	*percent*	*percent*	*percent*
1090	3	1	159.0	149.6	90.3	2.52			16.4			
		2	145.5	137.1	82.4	2.51			16.2			
		3	145.3	137.0	82.3	2.51	2.51	2.62	16.2	16.2	4.4	20.6
1110	4 & 5	1	149.3	142.6	85.8	2.50			12.2			
		2	153.5	146.7	88.3	2.51			12.0			
		3	148.9	142.8	85.6	2.50	2.50	2.605	11.1	11.8	3.7	15.5
1130	6	1	142.2	136.6	81.8	2.49			10.6			
		2	152.7	147.9	87.9	2.48	2.48	2.58	9.7	9.6	4.0	13.6
1150	7	1	142.3	138.9	81.9	2.44			6.2			
		2	138.5	134.4	79.5	2.45			7.7			
		3	154.3	149.8	88.7	2.45	2.45	2.545	7.6	7.2	4.0	11.2
1170	8	1	145.2	143.3	83.4	2.39			3.3			
		2	143.5	141.7	82.2	2.38			3.2			
		3	146.2	144.0	83.9	2.39	2.39	2.525	3.8	3.4	5.2	8.6
1190	9	1	140.0	138.9	80.5	2.38			2.0			
		2	151.6	150.8	86.9	2.36			1.6			
		3	146.0	144.7	83.9	2.38	2.38	2.520	2.2	2.0	6.0	8.0
1210	10	1	142.2	141.6	81.4	2.35			1.0			
		2	145.1	144.4	83.0	2.36			1.2			
		3	147.0	146.3	84.2	2.35	2.35	2.510	1.1	1.1	6.4	7.5
1230	11	1	136.2	135.9	76.7	2.30			.5			
		2	144.8	144.4	82.1	2.31			.7			
		3	142.7	142.5	81.1	2.32	2.31	2.495	.4	.5	7.3	7.8
1250	12	1	147.6	146.8	81.0	2.23			1.4			
		2	144.3	143.4	79.5	2.24			1.5			
		3	146.4	145.1	80.5	2.24	2.24	2.480	2.2	1.7	11.1	12.8

DISCUSSION

Prof. Potts: What is the advantage of expressing the volume changes in the true clay volume other than that you get a higher ordinate in plotting the curves?

Mr. Bleininger: Because true clay volume does not change, of course, as would the exterior volume. There are a great many accidental features, such as evolution of gas, which change exterior volume. The suggestion is made to eliminate these errors and employ a constant that is as much a real constant as we can get.

Mr. Purdy: I was very much interested in noting the exceedingly large amount of open pores in the overburned samples and the increasing volume of open pores. I am very much surprised. I don't know how you got water into them.

Mr. Bleininger: These open pores, due to escaping gas, are open all the way from the surface to the interior of the brick, and a great many of them communicate. The water does penetrate the interior, although there is a certain portion, as shown by the diagram, where the pores are really enclosed.

Mr. Purdy: How was that data obtained? By actual tests?

Mr. Bleininger: Yes, in the case of greatly overburned materials, there is a certain source of error, of course, because of the large surface openings which could not be gotten around, but even considering the error, the amount of water absorbed was as indicated by the diagrams.

Prof. Orton: Is it not true that when you burn a clay too long past its maturity, it forms this coarse vesicular structure, and as the cooling progresses, the walls of these vessels frequently rupture so as to make a communicating pore system, though it was previously gaseous bubbles?

Mr. Purdy: In bringing the clay up to this vitrification point, as I understand you did, you would have decreased open pores and increased vesicular structure or enclosed pores, and then, carrying it from the vitrified condition of that clay up to the overburned, you would get again a reverse, i.e., some of these enclosed pores are becoming open pores?

Mr. Bleininger: Yes, sir.

Mr. Purdy: What is the value of studying the clay after it is overburned?

Mr. Bleininger: It is simply because we are rather curious to know whether the specific gravity was approaching a constant value. In other words, how closely we were approaching equilibrium, but, as you see from the values, we are far from it. That is really the main motive for this.

Prof. Orton: Right in that connection, Dr. Day beautifully pointed out in his talk the other day the fact that he was dealing with one end of the system, and we were dealing with the other end of it; but it is very seldom that in actual clay products, we ever get to an approximation of the quiet equilibrium, but I have once or twice seen a condition of that sort where clays had gone through this bubbling state and settled into quiescent glasses.

Mr. Bleininger: You will notice in one or two cases there is a beginning of subsidence, and we had hoped to get more of it, but did not.

THE USE OF COST FIGURES IN PLANT ADMINISTRATION

BY DWIGHT T. FARNHAM, SEATTLE, WASH.

CO-OPERATION THE BASIS OF AN EFFECTIVE COST SYSTEM

Every business man's magazine and every trade journal, to say nothing of the numerous list of publications devoted exclusively to system and accountancy, devotes considerable space to articles on cost-keeping. These are illustrated profusely with ruled forms and various sorts of diagrams, which display the author's skill as a draftsman, and give full play to his ingenuity in subdividing the operations of manufacture in novel and astonishing ways. This sort of work is so fascinating that the author cannot be blamed for losing sight of the real purpose of cost-keeping, as he so often does, and mistaking the trappings and appanages of costs for the real substance. The best cost system is the one which, with the least clerical work will enable the executive head of the plant to compare the cost of labor and material during one period of time with the cost of labor and material during a similar period of time, in the manner which renders it the easiest to correct methods of manufacture, and so lower the cost of production.

Such a system cannot be designed by the chief clerk or by the superintendent alone, but must be the result of their co-operative study of the problems of manufacture. The intelligent superintendent knows what he wants his costs to tell him. It is the province of the accountant to show him how this can be done accurately, and in a way practicable from the book-keeping standpoint. Many a superintendent regards cost as an unholy system evolved late at night by the book-keeping department for the express purpose of tripping him up and proving him a loafer, a liar or a grafter—possibly all three. Under the circumstances, we cannot blame him for his lack of faith in costs, and his proneness to fall back upon that ancient axiom in regard to the veracity of those who figure. If, on the other hand, instead of having a terrifying stack of ruled forms thrust upon him with instructions which, to him, seem to require an instant and thorough comprehension of the intricacies of the most complicated system of double

entry, his interest can be gradually aroused by the mention of the fact that the clay gang averaged ten cars per man every day last week, which was one car per day better than they had done for the three weeks previous, he is much more likely to become an ardent believer in costs and cost systems. In other words, if a cost system can be presented in its true light, that of a help to the active executive rather than a basis for blame by the superior, the spirit of co-operation and mutual help between the accounting department and the superintendent is much more likely to be engendered than where the true function of costs is misunderstood. The superintendent should be fairly clamoring for his costs; and where he is, the manager will never have to use them as a text for a lecture on the general worthlessness of that superintendent.

The cost system should originate in and be built to fit the business, not the business hammered and constrained to conform to the cost system. Many an expensive cost system has been discarded because it led to conclusions which the men actively engaged in the process of manufacture could prove to be erroneous. It must not only be born in the business and of the needs of the men at the heads of the manufacturing departments; but it must change continually, following closely the evolutions of the process of manufacture. This can only be accomplished by the active executive feeling the need of the system and keeping in closest touch with the department which turns out the figures. It is a case of co-operation throughout, the cost system being so constituted by the accountant as to be of real assistance to the superintendent, and the superintendent so feeling the need of the cost system as to render every possible assistance to the accountant. Without this co-operation the best system will fail.

SIMPLE VERSUS ELABORATE SYSTEMS

Many successful business men feel that an annual statement is sufficient in the way of a cost system. This has been aptly termed the "bag" system of accounting. The manufacturer in question, in effect, secures a sack and into it puts all the money which comes in, paying out from time to time such sums as are necessary, and at the end of the year dumps the bag and pockets the contents. This is all right unless the contents happen to

consist of an accumulation of I. O. U.'s. When things come to this pass, he either goes into bankruptcy or institutes a cost system which will analyze his business and show him where the leaks are. The other extreme is the cost system which is so complicated that the busy executive has no time to puzzle his way through its intricacies, and in consequence, disregards it, so that the business is just about as well off as if it had the "bag" system. The effective cost system of course lies somewhere between these two extremes. It is so designed as to bring out the really salient points and subordinate the mass of detail in such a way that details can be studied in time of need but may be disregarded when the business is running smoothly. This matter of the subordination of detail will be elaborated upon later. It is a good plan, however, to overhaul your cost system at least once a year and prune out such parts as can be dispensed with. What appeared as valuable data when it was first worked out very often becomes dead matter in a short time, and it is only by frequent and heartless scrutiny that the cost system can be kept at a high efficiency. Keep in mind continually that the cost of preparing this data is a dead weight on the business, and make every bit of the cost system work hard and produce results sufficient to justify its existence.

Another thing, the cost system should be simple enough so that the analysis of the business can be made before the actual details of manufacture for the period are forgotten. The autopsy must be performed before the murderer has had time to escape. If the executive does not secure his cost data until a couple of months after, he is not likely to feel like going out and praising his men—or the reverse—for something that occurred so long ago as to be lost in the dim forgetfulness of ancient history. It is a good thing to have some daily costs, so that the executive knows just where he stands on the more important operations each night. Perhaps it may be found advantageous to roughly figure certain department costs each week, and then at the end of the month the carefully compiled costs for the whole month will give the executive head the opportunity to sit down and calmly and coolly analyze the cost of operating each department with a view to increasing its efficiency, and so cutting down the total cost of production.

A SAMPLE SYSTEM

We are not discussing methods of cost-keeping—a subject which would fill a volume, and is too likely to wander off into hair-splitting distinctions. Our subject is the use of a simple cost system in such a manner as to get results. Furthermore, we are going to leave strictly alone all sorts of questions in regard to the distribution of overhead expenses, the nature of depreciation, etc., any one of which is a subject in itself. We are taking, for purpose of illustration, a cost system which has been used extensively in the East and West to keep track of the operations around a sewer pipe plant—say in what is known as a "one press shop." In order to make the matter clear, we will assume that the clay is delivered on the dump in mine cars, is ground in two dry pans, tempered in three wet pans, is made into small pipe by a press on the second floor, or into large pipe by a press on the first floor, dried on one of the three drying floors, and burned in twelve 30-foot kilns. Also, that the plant is equipped with standard boilers, a 200-H.P. engine, the usual conveyors and elevators, etc., and a miscellaneous crew consisting of about one-fourth intelligent labor and the balance what you can pick up for a dollar and a half a day. It may be stated that the costs used in the following tabulation are not actual, although they closely approximate the cost of labor and supplies obtaining in Pennsylvania and Ohio in 1905, with common labor at $1.50 for ten hours, coal at $1.50 to $1.75 per short ton, and clay at $0.50 per ton delivered.

These are the costs which will interest the superintendent when he sits down about the middle of the month following and carefully analyzes the cost of each operation for the month previous. During that month he has had daily reports showing the tons or list value of the pipe made each day, the number of hours run, the list per hour run, the cause of each shut-down, and the number of men in each department, possibly, also, the total wages for the day, so that he has known in a general way just how things have been going. Of course, any number of plants are run without this daily report, plants where the superintendent's efficiency[1] is judged

[1] In this paper we use the word "efficiency" to denote the amount of work done in a given time, taking the quality of the work, into consideration.

by the number of pairs of shoes he can wear out in a month and by the distance his voice can be heard. If you believe in that sort of plant administration, you probably stopped reading at the bottom of the first page, so that any discourse as to the errors of this type of superintending would not even reach you—much less convince you. For the benefit of those unfortunates who have to combat the advocates of the "shoe leather" system, it may be as well, however, to point to the common sense analysis of the matter. There are at least ten separate departments covered in the following tabulation—ten different gangs of men. This means that the harrassed foot racer who is responsible for the efficiency of the work of each crew can devote just one hour of the ten to each department—while the other nine hours each crew does as it pleases.

We are not discussing the organization of the plant, the relations of the superintendent to his various foremen and sub-foremen; but we have always believed that a plant should be so organized that it will run itself as far as the routine work goes, leaving the superintendent free to throw himself into the breach where his superior training and knowledge are most needed. During those rare times when there is no "trouble" anywhere, he can put his feet upon his desk and figure out how the company can make more money.

At any rate, the superintendent can only be in one place at a time, and his chance of keeping all his crews working at a high efficiency is greatly increased if every night, or early the next morning, he is handed a slip of paper which tells him just what each crew has accomplished during the day. The company's position is also much more secure where a careful record of this sort has been kept. When a superintendent drops out, he does not take all the experience he has gained at the company's expense with him. There are records which the next man can profit by, and there is less chance of the plant being turned into an experimental station for the education of superintendents.

The costs for a single month are of little value taken alone. It is when they are compared with the preceding months and the fluctuations noted, and the investigations on the yard begun, that a cost system begins to pay dividends. The cost of grinding is

higher; why? It is lower; why? The answer leads to a reorganization of the crew, or to the installation of labor-saving devices, and when the cost of the operation ceases to show violent fluctuations and remains uniformly low, the superintendent can tackle another problem. It is a very good plan for the superintendent to plot his costs on graph paper; then he has the whole thing spread out before him and fluctuations are much more noticeable.

One of the first things to do, once the system has been installed, is to determine the relative importance of the various operations. It will be noted that this phrase heads the third column in the tabulation. After the costs for the month have been determined, it is a good thing to figure out just what percentage of the whole cost is represented by the cost of each operation. The various operations are then given numbers as in the third column, which show their importance in the scale. This brings home to the student the importance of concentrating his attention upon certain operations.

The superintendent must keep in mind that he is the highest priced man about the place, that his time is worth more per hour than that of anyone's under him, that he is paid this for his brains, and that he must concentrate the full power of these brains upon the things which will save the company the most money. To do this intelligently, he must know in which operation a saving of 5 percent will net the most. If he concentrates on the stable and saves 5 percent of the cost, his work means one and a half mills per ton, $0.60 per month to the company. If he concentrates on the kiln coal, this five percent may mean four cents per ton or $60 per month. He must know how to conserve his time, how to pick out the essentials, and to concentrate on those. That is the reason for the third and fourth columns.

This knowledge of the relative importance of things is one of the most difficult things for a foreman to learn. It is so easy when a workman is doing a thing clumsily or carelessly to "jump in and show him how," while the laborer stands by with his tongue in his cheek—and gets a rest—that some foremen have to be watched continually or they will do manual labor most of the time. It is easier to shovel than to think, in spite of what the soap box orators say, and the three dollar foreman has to learn that

every time he takes a dollar and a half man's job away from him he is robbing the company of just fifteen cents per hour. I have seen a foreman go roaring into the midst of a crew of men and by superhuman exertion do the work of two or three of them for twenty minutes, while they all stood by and laughed in their sleeves, order them "to do it that way" and strut off with the sweat fairly dripping from him, thinking he had really accomplished something, while the men continued the work at exactly the former gait. And the worst of it is, lots of superintendents, and owners, think such a foreman is a valuable man. Why, he was robbing the company just as surely as if he had looted the cash drawer. If he had stood and watched this crew fifteen minutes—and thought —and then spent five minutes re-grouping those men, possibly taken away or added a man to the crew, put one of them on work for which he was better suited mentally or physically, shown one of them how to handle his tools more efficiently, he would have been earning his salary, and the men would have thought more of him.

EXAMPLES OF THE USE OF A COST SYSTEM

It will not be possible to analyze each operation given in the accompanying tabulation. One or two examples, will, however, be sufficient.

We will begin with No. 1, kiln coal, which costs say $1.60 per ton, and of which half a ton is required to burn a ton of burned sewer pipe. The question is how to reduce this cost of $0.80 per ton. Perhaps we can buy a cheaper coal and by careful attention to the details of burning, bring off our kilns with the same amount of coal without decreasing the quality of our ware. Perhaps we can use a coal that costs more per ton, but of which so much less is required that the ultimate cost per ton of burning ware is cheapened. In either case the saving is immediate.

While making these tests we must carefully weigh or measure the coal and the ashes so that we do not lose what we gain in coal cost by an increased stable cost, or by having to increase our burning force on account of the extra coal and ashes to be handled, or on account of the extra difficulty of cleaning fires because of the greater tendency of the new coal to clinker and stick to the brick work.

TABULATION—SHOWING MONTHLY COST OF LABOR AND MATERIAL IN A SEWER PIPE FACTORY

OPERATION	COST PER TON	PERCENTAGE OF TOTAL	RELATIVE IMPORTANCE OF OPERATIONS
WAGES			
Moving clay—cars to dry pans	$0.03	0.8	12
Grinding—dry pans	.06	1.6	9
Mixing—wet pans	0.5	1.3	10
Making press crew	.34	9.0	4
Finishing and drying—floor crew	.12	3.4	7
Setting—floor to kiln	.25	6.6	5
Burning—burners and firemen	.20	5.3	6
Hauling coal and ash—carts and horses	0.3	0.8	12
Kiln cleaning—cleaning	.02	0.5	13
Drawing—kiln to yard or cars	.25	6.6	5
General labor—miscellaneous	.10	2.6	8
Repairs to buildings	.03	0.8	12
Repairs to machinery and equipment	.07	1.8	9
Repairs to kilns	.04	1.0	11
Repairs to tools	.01	0.2	14
Superintendence	.12	3.4	7
Total labor	$1.72	45.7	
SUPPLIES			
Repairs to buildings	$0.04	1.0	11
Repairs to machinery and equipment	.05	1.3	10
Repairs to kilns	.10	2.6	8
Repairs to tools	.01	0.2	14
Miscellaneous supplies	.07	1.8	9
Stable—labor and supplies	.05	1.3	10
Clay—cost at storage	.50	13.2	2
Kiln coal—cost in bunkers	.80	21.2	1
Steam power—labor, coal and supplies	.40	10.6	3
Total supplies	2.02	53.2	
Total labor and supplies, cost per ton	3.74	100.0	

NOTE: At $3.75 per ton, sewer pipe will cost from 8 to 9 percent of the list for labor and supplies, which will bring the total cost sold, f.o.b. cars at plant, up to 13 or 14 percent of the list or card.

The second method of decreasing the coal cost per ton of ware burned is by a careful analysis of the burning. For all practical purposes the rule is a safe one that the quantity of coal burned varies directly as the hours the kiln is burned. The quicker you can burn off your kiln of ware, the less coal you will use. Economy along this line means an intimate knowledge of the clay being treated, and progress must be slow if heavy losses are to be avoided.

For the sake of brevity, we will say the burning of this particular clay divides into the three simple periods, water smoking, oxidation, and vitrification, the first period extending from the atmospheric temperature to 650°C., the second from 650° to 750°, and the last from 750° to 1100°.

A pyrometer is not absolutely necessary; but with it you will reach your conclusions much more rapidly and with less loss, and you can reproduce a given set of conditions with much greater accuracy.

We will assume that the burns have been satisfactory as far as the quality of the ware is concerned. Our object is to cut down the time—and coal—and still hold the quality. Needless to say, we make sure the kilns to be used in the test are clean and in good condition, and that all ware set is thoroughly dry.

We begin by cutting down the water smoking period, say a three hour period at a time, until we have a few blown pipe, then we stop, completing each burn and studying the results before beginning another experimental burn along the same lines. Meantime, in order to save time, we may have been cutting down the oxidation on another kiln, and the vitrification period on another. It is best not to shorten two periods on one burn lest the troubles arising be laid to the wrong period.

By a careful process of elimination, making sure always that the burning conditions are as uniform as possible, the time is reduced, first in the three hour periods, and later by hour periods, until the shortest safe burn is determined, and the lowest coal consumption established. I knew an old burner once who said he was never sure he had cut his coal to the limit unless he had one slightly blown pipe, and one slightly swelled pipe, when the kiln was drawn. This is skating on pretty thin ice, however, and is not advised. By careful work it is possible to establish a regular

schedule for burning dry pipe, one slightly longer for damp pipe, and one which is safe when, as sometimes happens, the pipe are set very damp, and for the head burner to hold his foremen to these time tables with very little variation. Such a system, once firmly established, insures the lowest practicable coal consumption.

The second highest item on the tabulation is clay. In order to cheapen this, the superintendent must go out of his province under the factory conditions we have outlined. Even so, it is advisable for him to take an intelligent interest in the clay mining. He may be able to use a clay which can be more cheaply mined, or he may by insisting on a more careful selection, be able to increase his percentage of No. 1 ware.

The third item is important; steam power is worthy of the deepest study. The purchase of coal should be given close attention as in the case of the burning. The field is, however, somewhat wider, as we have no percentage to contend with. We can use the cheapest coal we can buy, provided the extra amount required does not cost more than is saved by the cheaper price per ton, and provided additions to the firing crew can be avoided.

By the use of dutch ovens and mechanical stokers, refuse coals can be used, which cost little or nothing. These solve the labor problem and cut the firing expense to a minimum. By the use of such a device, six hundred horse power can be handled by two men, using coal 75 percent of which will pass a 20-mesh screen. The chance for investigation and improvement in the usual clay-plant boiler room is almost unlimited, and as we have seen, a saving here is the third most important saving about the plant.

The fourth item, making, is largely a matter of output, and this is by long odds the most important thing to watch about the plant. We have seen how the careful superintendent has kept watch of his output with his daily reports. The effect of increased or decreased output, not only upon the making but upon the whole cost, is perhaps best seen by means of the following calculation. In the tabulation the cost per ton is found by dividing the monthly wages by the tons processed. We have assumed a making divisor of 1200 tons (monthly production at press). This divisor is properly used in the following operations:—grinding (the same number of men operate the dry pans regardless of whether

50 or 70 tons of clay are ground in a day, etc.) mixing, making, finishing and drying, general labor, repairs to buildings, machinery and tools, and superintendence. The supplies divided by the tons made would properly be supplies for repairs to buildings, to machinery, and to tools, miscellaneous supplies, stable and steam power. Some other items would be affected by the output, such as burning, etc., but we have left these out to offset any slight additional labor required by an increase in output in the operations enumerated above. The cost added to a ton of clay when acted upon by the above departments is shown in the tabulation for 1200 tons as $0.90 for labor and $0.62 for supplies or $1.52. Multiplying this by 1200 tons, we find the pay roll for these items for the month amounted to $1080, and the bills for the supplies to $744. Therefore, for $1824 we put 1200 tons through these departments.

If, now, our output had fallen to 1000 tons, inasmuch as the cost of maintaining these departments is the same, whether we put through 1000 or 1500 tons, our cost per ton would have risen $0.30 ($1824 divided by 1000 equals $1.82 per ton, less $1.52 equals $0.30) and we would have lost approximately $300 at the plant, to say nothing of the profits on the other 200 tons of ware we did not make.

On the other hand, if we had turned out 1500 tons our cost per ton for these operations would have fallen to $1.21, a saving of $0.31 per ton or $465. Therefore, if we make 1000 tons instead of 1500 tons we lose about $765 during the month at the plant alone. It is very evident why a man who can maintain the quality of the ware and at the same time boost the output to the limit at all times is always in demand as a superintendent.

The two items which rank fifth, drawing and setting, are largely a matter of kiln location and yard arrangement.

Burning has been discussed in connection with coal economy. Superintendence and finishing, in seventh place, have been touched upon in connection with output.

General labor should be kept as low as possible, inasmuch as it is likely to lead to abuses on the part of foremen; and you never know just what comprises this item, so that the charge is not comparable from month to month. If you require your foremen

to enter on each man's card just what he was doing during the day, you have a check on the foreman's methods, and loss is often avoided. Nothing should ever be entered under the head of general labor except in the factory office.

Kiln repair supplies and labor are largely a matter of kiln building. A considerable saving can often be effected, however, by changing the quality of the fire brick used for repairs and by always keeping firmly in mind the old adage that "A stitch in time saves nine."

The items ninth in importance have been covered in connection with output, as have also the tenth, and repairs to buildings under eleven.

Moving clay is largely a matter of proper dumping, conveying and storage facilities. Hauling coal is similarly dependent upon mechanical and storage equipment. The cost of hauling ashes is governed by the distance the dump is located from the kilns. It is a good plan to follow up your cartmen with a stop watch occasionally while you are measuring your ashes on a coal test. You may not by so doing save a man, but you may save enough of his time to keep your yard cleaned up and get a good many odd jobs attended to.

CONCLUSION

We have indulged in some generalities, and we have covered briefly a few specific operations; sometimes it has been necessary to sacrifice clearness to brevity. An exhaustive discussion would fill a good many hundred pages. In summing up, we cannot dwell too strongly upon the necessity of mutual trust and co-operation between the accounting and operating departments. The superintendent's problem is to realize what is most vital about a plant and then to concentrate on that. Output and quality he must keep always before him. Efficiency means these two coupled with common sense in labor matters, and if it is not too much to ask, a little mechanical ingenuity and on occasion the gift of prophecy—and the surest prophecy is grounded upon a study of past events as shown by intelligently prepared cost figures.

A COMMERCIAL METHOD OF TESTING FELDSPAR

BY J. MINNEMAN, BARBERTON, O.

INTRODUCTION

It had formerly been the custom of the writer to test each incoming car of feldspar by making up a small cone of the sample and firing this against a similar cone made from a stock of feldspar considered as a standard. The writer understands that this method is a common one both with feldspar grinders and potters. By this method very little variation was noticed between any shipments, though at times it seemed as though there was some variation, judging from the action of the ware in the kilns.

As samples of new feldspars were received from different miners these were tested in the same manner. Upon examination of the analyses of these new samples, and a calculation of their approximate mineral compositions, it seemed that a wider variation in deformation temperatures should be expected than was found by this method of testing. The mineral compositions also showed much greater quartz contents than were expected; and knowing that rather large variations in the quartz content of a feldspar make but slight changes in the deformation temperatures, up to a given quartz content, the following trials were undertaken to determine this point definitely.

EXPERIMENTAL PART

Discussion of Samples. Four different feldspars were tested, coming from various parts of the country and representing fairly well the various types of feldspars on the American market.

Sample A. A feldspar from Sagadahoc County, Maine, occurring as a pegmatite made up of microcline and a darker colored albite graphically intergrown with quartz intergrowths varying from very small particles, to pieces the size of one's hand.

Sample B. A feldspar from Middlesex County, Conn., occurring as a rather fine grained graphic pegmatite made up of greenish microcline and albite intergrown with quartz.

Sample C. A feldspar from the Province of Ontario, Canada,

about thirty miles north of Kingston, a pure microcline feldspar cut by quartz dykes.

Sample D. A feldspar from Westchester County, N. Y., occurring as an irregular pegmatite made up of pink microcline and whitish albite intergrown with quartz.

Analyses. The writer not being in position to make an ultimate chemical analysis, the analysis furnished by the miners for the respective samples were taken as a basis of calculation. The ultimate analyses are shown in Table I and the calculated approximate analyses in Table II.

TABLE I—CHEMICAL COMPOSITIONS OF THE SAMPLES

	A	B	C	D
Silica	70.78	69.68	65.25	71.00
Ferric oxide	0.14	0.13	Trace	
Alumina	16.76	16.86	18.68	18.80
Lime	0.25	0.29	0.40	0.40
Magnesia	0.16	0.09	0.23	0.05
Potash	8.13	10.98	13.40	6.20
Soda	2.72	1.66	1.99	3.25
Water	.80			
	99.74	99.69	99.95	100.00

TABLE II—APPROXIMATE MINERAL COMPOSITION OF THE SAMPLES

	A	B	C	D
Quartz	24.01	18.42	0.07	28.50
Potash feldspar	49.87	62.41	78.10	35.38
Soda feldspar, some lime	24.78	17.56	21.44	32.03
Other constituents	1.10	1.60	0.37	4.09
	99.76	99.69	99.98	100.00

Size of Grains. The samples were first tested for fineness by washing successively through a 120, 150 and 200-mesh sieve, with the results shown in Table III.

Making the Tests. Mixtures of the feldspar with flint were now made up. Starting with straight feldspar, the flint was increased by increments of 5 percent until 25 percent flint was reached in

TABLE III—SIZE OF GRAIN OF SAMPLES

SAMPLE	RESIDUE ON 120-MESH	RESIDUE ON 150-MESH	RESIDUE ON 200-MESH	TOTAL RESIDUE ON 200-MESH SIEVE
	percent	*percent*	*percent*	*percent*
A.....	0.19	0.05	0.65	0.89
B.....	0.23	0.06	0.55	0.84
C.....	0.20	0.15	1.35	1.70
D.....	0.10	1.10	4.60	5.8

each case. The flint used was furnished by the Ottowa Silica Company, Ottowa, Illinois, ground to leave less than 1.5 percent on a 200-mesh sieve. The mixtures were made by grinding the feldspars and flint together in a mortar with water, until a thorough mixture was obtained. They were then made up into cones similar to the pyrometric cones of commerce. The mixtures are designated by letters and figures as shown in the Table IV.

TABLE IV—COMPOSITIONS TESTED

FELDSPAR..... FLINT.....	100 0	95 5	90 10	85 15	80 20	75 25
Feldspar A.....	A	A1	A2	A3	A4	A5
Feldspar B.....	B	B1	B2	B3	B4	B5
Feldspar C.....	C	C1	C2	C3	C4	C5
Feldspar D.....	D	D1	D2	D3	D4	D5

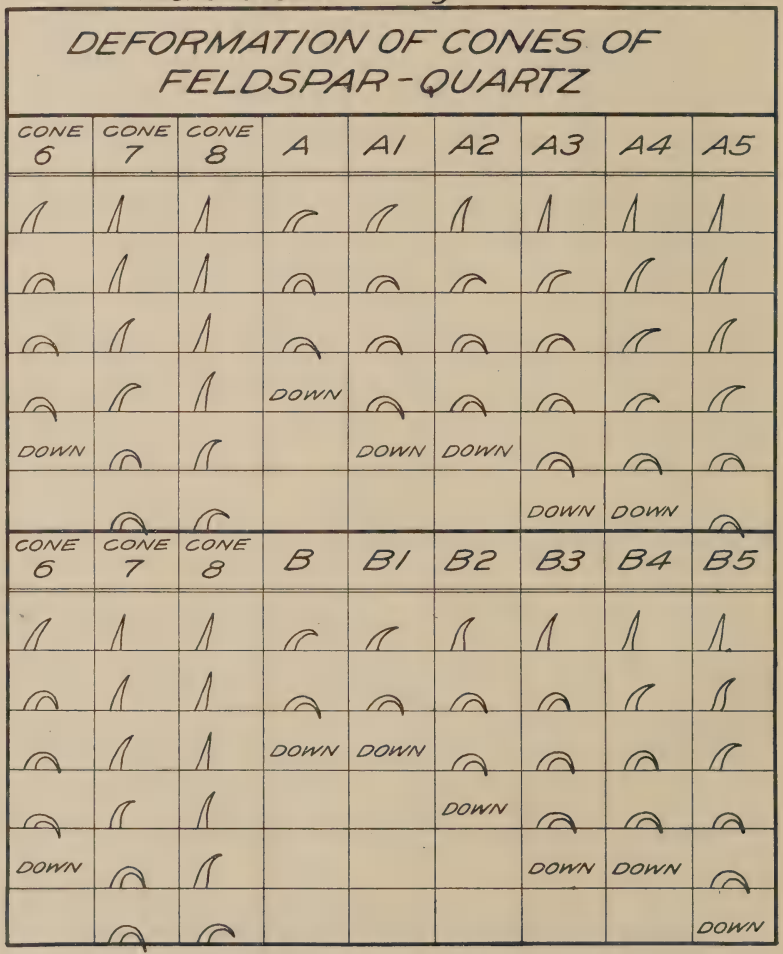
The trials were fired in a commercial, updraft, potter's kiln against standard pyrometric cones 6, 7 and 8, in a 48-hour burn. Figures 1 and 2 show the relative temperatures and deformations of the various mixtures.

Discussion of Results. It will be seen that there is noticeable deformation with all the feldspars when cone 6 is barely started, and Sample C, which is practically free from quartz, is almost touching at this heat, whereas, Watts[1] found that with pure microcline feldspar deformations started at cone 8. It must, however, be remembered that Watts was working with a pure potash feldspar, while all these trials contain considerable soda.

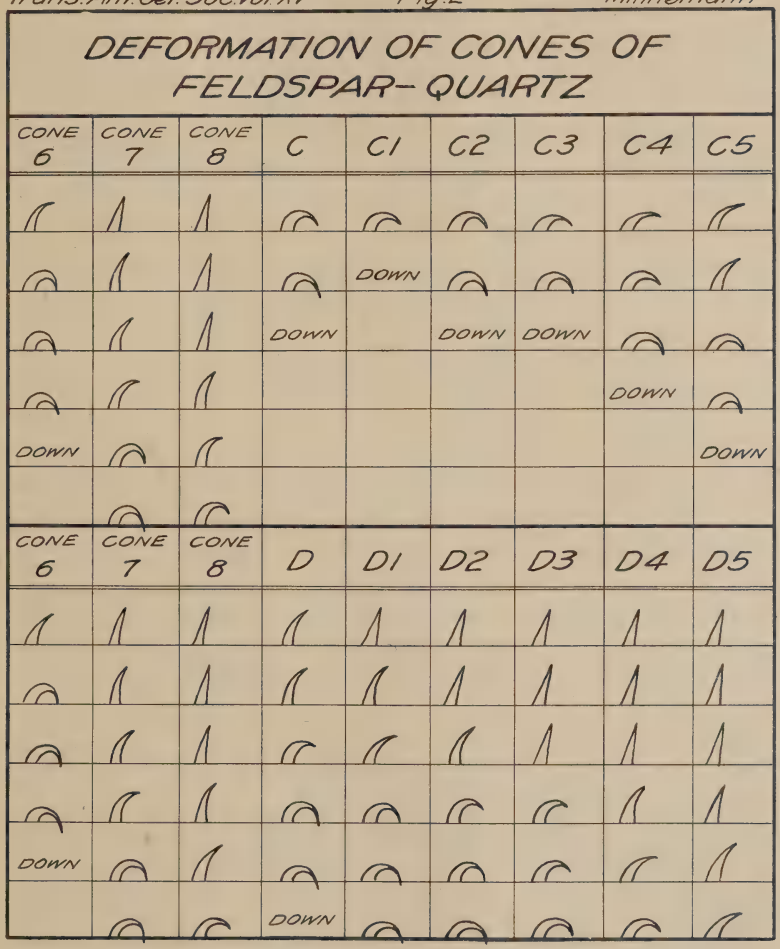
Series A and B, in which the quartz varies from about 20 to 40 percent, show a continual decrease in deformation at all heats

[1] *Trans. A. C. S.*, vol. 14, p. 87.

Trans. Am. Cer. Soc. Vol. XV Fig. 1. Minnemann



Trans. Am. Cer. Soc. Vol. XV Fig. 2 Minnemann



with an increase in quartz. Series D in which the quartz varies from 30 to 50 percent shows the same action. Series C, however, with from 0 to 25 percent quartz shows no appreciable change in deformation until 15 percent quartz is reached; but above this there is a decrease in deformation.

Method of Testing Adopted. The writer has tested shipments of feldspar received for several years, bearing in mind these trials, and has adopted the following method of testing.

1. A sample from each car is lawned through several different sized sieves, taken as standards; any shipment deviating materially from the fineness adopted is rejected.

2. Cones, of the size and shape of standard pyrometeric cones, are made up from the sample of feldspar, together with a given amount of flint (from 15 to 20 percent). These cones are fired in commercial kilns against cones of a similar mixture made from a stock of feldspar considered as a standard.

3. The fired cones are examined for color and the presence of black specks.

Where possible, it is advisable to have bin capacity sufficient that an incoming car can be unloaded and not used until tests are completed. Feldspar grinders are also generally willing to mail a sample of feldspar from the car they are shipping a customer, so that tests can be finished by the time the car arrives.

This method of testing is only intended to determine the existence of any variation in the feldspar. If a variation in color or fusibility is found, the shipment should of course be set aside until complete tests are made. In such a case a chemical analysis is invaluable when supplemented by a series of deformation trials with various mixtures of flint, fired against the standard stock of feldspar at different heats. Small batches of the body made with the doubtful feldspar should also be fired. When the variation is in the quartz content, a correction for this may be made in the mix.

While feldspar grinders do not, as a rule, vary their product intentionally, and in fact serious variations are few and far between, still, mistakes are sometimes made, and their detection in a single case will pay for years of seemingly fruitless testing.

CONCLUSIONS

1. When quartz is added to pure feldspar, very little change in the deformation is noticed until about 15 percent quartz is reached, after which the deformation is decreased with an increase of quartz.

2. The ordinary method of testing feldspars, by melting a small amount of the sample, will not detect variations of from 5 to 15 percent in the quartz content, although it is evident that such a variation would make a considerable difference in the ware.

3. If the quartz content of the feldspar is increased until the total amount of the free quartz is 25 percent or more, then any additional quartz above this amount is easily noticed when a trial cone is fired against one containing this fixed amount. A decrease of quartz would likewise be noticed.

4. Contrary to the common opinion that the presence of quartz in feldspar is not permissible; the greater part of the feldspar on the American market contains a considerable amount of free quartz.[2]

5. The purchaser of feldspar containing a considerable amount of free quartz is liable to encounter considerable variation in the quartz content, due to variable sorting of the crude material, and in addition is paying for a certain amount of quartz at the feldspar price.

6. Any variation in color or fusibility which would affect the ware will be found by the method of testing described above.

7. When any variation is found, the more complete tests mentioned should be carried through.

DISCUSSIONS SUBMITTED AFTER READING THE PAPER

Mr. Watts: I have read with much interest the paper which Mr. Minneman presents, and feel that in the main his method is very good; but it lacks the ability to furnish data on the actual operation of the feldspars for pottery mixtures. While the information as to the relative deformation temperatures of feldspars is exceedingly valuable as a means of comparing different feldspars, the

[2] *Trans. A. C. S.*, vol. 14, p. 87.

manufacturer is very much more interested in the operation of a feldspar in a pottery mixture; and for that reason, it appears to me that this process would be much more valuable if to it were added the testing of mixtures of these feldspars with standard amounts of clay and flint. No feldspar is used in the industries with additions of flint only; and the data on the deformation temperature of feldspar with quartz additions is apt to be misleading, without the trials made up in commercial mixtures.

The point which I desire particularly to raise regarding this article of Mr. Minneman's is the temperature of deformation which he gives us on these four representative feldspars. Mr. Minneman finds that a Maine feldspar containing 24 percent quartz begins to deform below cone 6 and a mixture of this feldspar plus quartz having a norm composition of 60 percent feldspar and 40 percent quartz deforms ahead of cone 8.

I have just completed tests of about thirty Maine feldspars, which I took from the deposits in that state during the past year. I have been unable to find a feldspar, which in any way approaches the composition set down by Mr. Minneman, deform below cone 7. In the purest possible state in which I could obtain it and with the quartz content that is normal to these feldspars, the majority of them deform slightly higher than cone 8. Other users of feldspar bear me out in this statement; and I feel certain that there must be a conflict between Mr. Minneman's data and the universal experience of others if he can make a Maine feldspar containing 24 percent of free quartz deform below the deforming temperature of cone 6.

Regarding the Connecticut feldspars, I have sampled every workable deposit now open in the state of Connecticut and have just completed tests on same, and find that, of the feldspars which in any way approach the composition set forth by Mr. Minneman, none begin to deform until cone 6 has touched the plate. This data is on the pure feldspar; and the addition of quartz to feldspars of this type does not materially reduce the deformation temperature, but merely affects the rate of deformation. The feldspars that are commercially ground in Connecticut do not, in my experience, deform at lower temperature than cone 8.

Regarding the Canadian feldspar, which Mr. Minneman re-

ports as deforming slightly ahead of cone 6, I would say that I have never been able to get such a feldspar from Ontario, Canada, and I used feldspars of that district for about six years on an extensive commercial scale. The Canadian feldspars are generally agreed to deform slightly above cone 7 and probably nearer cone $7\frac{1}{2}$. This is a feldspar from Ontario which analyses 3 percent soda as compared with Mr. Minneman's analysis which shows 1.99 percent of soda.

The foregoing indicates to me that the discrepancy between Mr. Minneman's data and the data of every one else who has worked on these feldspars must be due either to the cones which he is using as standards or to the method which he employs in the firing of the kilns in which the tests were made. It hardly seems possible that the method of firing of any ordinary potter's kiln in which the burning period does not exceed 48 hours could cause a discrepancy of one to two cones in the deforming temperature of these commercial feldspars.

Mr. Minneman: In regard to the method of testing, I have not attempted to recommend this method as a safe method of testing different kinds of feldspars to determine which is the better for the potter to use, as it would seem from Mr. Watts' discussion; though I agree with him that in this connection it would be quite valuable, supplemented by actual body mixes.

I do, however, claim that this method of testing each shipment of feldspar will tell the purchaser what he wants to know. The potter using a certain feldspar from a certain miner should know whether the incoming shipment is the same as the last, or as the feldspar he had last year. The property which is most apt to vary and which is the most serious in case of variation is the fusibility, and I find that in testing feldspar with an addition of flint this variation in fusibility is easily detected. To add small amounts of clay to the mixture would be of no avail except to harden the mixture, making it more difficult to determine the fusibility or deformation, for I do not know of anyone who has observed an eutectic between clay and feldspar.

I do not find it satisfactory to test feldspar by making the sample up into the body mix itself, owing to the fact that small variations in the vitrification of a body are very difficult to detect

with the eye, though they may be quite serious in the extremes of the heat range of the kilns.

As to the discrepancy in the deformation temperatures cited by Mr. Watts between my data and the "data of everyone else," I have not been able to find any published data with the exception of an article by Mr. Watts in Volume XIV, on the deformation of feldspar. However, considerable work has been done on the melting points of feldspars; probably the most recent and reliable being that of Day and Allen from the Geological Laboratory of the Carnegie Institute.[3]

In determining the melting point Mr. Day and Mr. Allen found the temperature at which heat was absorbed by the sample of feldspar being tested, when changing from the crystalline to the amorphous condition. When a sample of orthoclase feldspar was heated for 100 minutes the change began at 1135°C. (cone 01) and was complete at 1275°C. (cone 7), being then melted (in the amorphous state). When heated more slowly, 160 minutes, the change was complete at 1200°C. (cone $3\frac{1}{2}$). In melting a sample of orthoclase from Mitchell County, North Carolina, they found the sample to be sufficiently softened at 1150°C. (cone 1) to be deformed under a slight continued pressure, and at 1225°C. (cone 5) to be completely amorphous. When a feldspar of this type, in its purest form, is sufficiently softened at the temperature of cone 1 to be deformed under a slight pressure, when heated for a short time only, it seems strange to me that Mr. Watts should see no natural deformation before cone 8 when firing for a long time.

In regard to the opinions of feldspar users, I find that many potters test feldspar by making a cone whose base is about equal to the heighth, these are fired on a level slab, and consequently no deformation is evident until a much higher temperature is reached.

Mr. Watts' experience to the contrary, I have repeatedly taken trials of the Canadian feldspar C and the Maine feldspar A from different shipments and fired them in a number of different commercial burns, varying from 48 to 55 hours against standard

[3] *Am. Jour. Sci.*, 4th ser., vol. 19, pp. 93-142, 1905.

pyrometric cones taken from various lots and have invariably found the cone of the Canadian feldspar to be touching the plate when cone 7 showed no sign of deformation, and the cone of the Maine feldspar touching at the first sign of deformation of cone 7.

There is no doubt that a difference exists between the heat action of a commercial kiln and that of a laboratory test kiln, for this point has been repeatedly reported. I have made a number of deformation tests in these feldspars in a laboratory test kiln in which cone 4 was reached in about two hours and cone 7 in four hours. I found that as a general thing the deformation points of the feldspars were raised about one cone above that found in our commerial kilns. But even in this test kiln I find the Maine feldspar begins to deform slightly above cone 7 and the Canadian somewhat below cone 7.

A SIMPLE GRAPHIC METHOD OF RECORDING THE OPERATIONS OF KILNS

BY F. H. RIDDLE

Maximum production is the great desire of most manufacturers and is of vital importance where the margin of profits is small, as in most branches of the clay business. In most cases, particularly in the older factories, it will be found that one department is holding back the rest and that processes are unbalanced. In a good many cases this is the fault of not having machinery of great enough capacity and can be righted only by an investment of considerable money for new machinery. When, however, the trouble seems to be in the management of the burning, a proper system of kiln records is a great aid in overcoming such lack of co-ordination.

On single yards with a good many kilns, it is important to have simple records so that the superintendent, manager and head burner can tell what is going on. If the head office of a company operating several factories is at a considerable distance from the plants, it is especially important to have proper daily reports that will make it possible for the office to know what is going on and, if things are not as they should be, why.

If reports keep coming in that the shop is shut down—"Out of kiln room," it will appear that the factory has not sufficient kilns to keep up with the inside processes. This will be especially obvious if any reports come to the office stating the time the kilns were on fire and showing that the burning time is normal. If the burning time is shown to be too long, it is evident that the kiln capacity can be increased by shortening the time of burning. Again, in a good many yards, two or even three kilns will be ready to draw at once, and can not be, because there are not enough men in the drawing crew. The next week the pay roll of this factory will show that the drawing crew was laid off because there were no cool kilns. How many companies can look in the factory report books and tell, not only how long the kilns burned, but also how long they took to cool? Finally a report that shows idle kilns is well worthy of study.

Fig. 1.

LOG OF KILN OPERATIONS IN SEWER-PIPE YARD

Trans. Am. Cer. Soc. Vol. XV — Fourteen Kilns, March 1913 — Riddle

Kiln	1	S 2	3	4	5	6	7	8	S 9	10	11	12	13	14	15	S 16	17	18	19	20	21	22	S 23	24	25	26	27	28	29	S 30	31	Total
1	F 4	F 5	F 6	F 7	F 8 4D	C	C 1	C D	C	D	S	18D 1 F	F 2	F 3	F 4	F 5	F 6 4½	C	C 1	C D	C	D	◉	S	F 8" 1	F 2	F 3	F 4 4T	C 5	◉	C	2
2	D	◉	S	F 22" 1	F 2	F 3	F 4	F 5	F 6	F 7 5S	C	C 1	C D	C	D	◉	S	F 8" 1	F 2	F 3	F 4 4D	C	C 1	C	C	C D	D	S	F 1	F 2	F 3	F 4	3
3	C D	C	D	S	F 8" 1	F 2	F 3	F 4 4½	C 1	C D	C	D	S	F 12" 1	F 2	F 3	F 4	F 5 4S	C	C 1	C D	C	◉	D	S	F 10" 1	F 2	F 3	F 4	F 5	F 6	3
4	8	C	C 1	C D	C	D	S	F 12" 1	F 2	F 3	F 4	F 5	C	C 1	C D	C	D	S	F 22" 1	F 2	F 3	F 4	F 5	F 6	F 7 3D	C	C 1	C D	C	◉	D	3
5	C	C 1	C D	C	D	S	F 24D 1	F 2	F 3	F 4	F 5	F 6	F 1	F 8 4D	C	C 1	C D	C	D	S	F 24" 1	F 2	F 3	F 4	F 5	F 6	F 1	F 8 4T	C	C 1	C D	2
6	S	F 22" 1	F 2	F 3	F 4	F 5	F 6	F 7 4D	C	C 1	C D	C	D	S	F 8" 1	F 2	F 3	F 4 4S	C 5	C 1	C D	C	◉	●	D	S	F 1	F 2	F 3	F 4	F 5	2
7	C 1	C	C D	D	S	F 10S 1	F 2	F 3	F 4 4T	C	C 1	C D	C	D	S	F 10" 1	F 2	F 3	F 4 5S	C	C	C	C	D	S	F 8" 1	F 2	F 3	F 4 3D	C	C	3
8	F 18D 1	F 2	F 3	F 4	F 5	F 6 3D	C	C 1	C D	C	D	S	F 8" 1	F 2	F 3	F 4 4D	C 1	C	C D	C	D	S	F 18D 1	F 2	F 3	F 4	F 5	F 6 4T	C	C	C	2
9	S	C	C 1	C	C D	C	D	S	F 12" 1	F 2	F 3	F 4	F 5 4T	F	F 1	C D	C	D	S	F 10" 1	F 2	F 3	F 4	F 5 4S	C	C 1	C D	C	D	◉	S	3
10	F 3	F 4	F 5	F 6	F 7	F 8	C	C	C	C	D	S	C	C 1	C D	C	D	S	F 8" 1	F 2	F 3	F 4 4½	C	C 1	C	C D	C	S	F 1	F 2	F 3	3
11	C	C	C	D	S	F 10" 1	F 2	F 3	F 4 4T	C	C 1	C D	C	D	S	F 24" 1	F 2	F 3	F 4	F 5	F 6	F 1	F 8 3D	C	C 1	C	C D	C	D	S	F	F	3
12	F 6	F 2	F 8 3D	C	C 1	C D	C	D	◉	S	F 12" 1	F 2	F 3	F 4	F 5 5T	C 6	C 1	C D	C	D	S	F 24" 1	F 2	F 3	F 4	F 5	F 6	F 7	F 8 5S	C	C 1	2
13	D	◉	S	F 10" 1	F 2	F 3	F 4 4D	C	C 1	C	C D	D	S	F 24" 1	F 2	F 3	F 4	F 5	F 6	F 7	F 8 3D	C	C 1	C D	C	D	S	F 1	F 6	F 3	F 4	3
14	C	C 1	C D	C	D	S	F 24" 1	F 2	F 3	F 4	F 5	F 6	F 7	F 8 4D	C	C 1	C	C D	C	D	S	F 10" 1	F 2	F 3	F 4 4D	C	C 1	C D	C	D	◉	S	3
Draw	2		1	2	2	1	1	1		1	2	2	1	2	1		2	1	2	1	1	1		2	1	2	1	1	2		1	37
Set	1		2	1	2	2	1	1		1	1	2	2	1	2		1	2	1	2	1	1		1	2	1	2	1	1		2	37

S = Being set, F = Being fired, C = Cooling, D = Being drawn, ● = Kiln idle, ◉ = Kiln idle on Sunday, C^T = Cooling and door tapped, C^D = Cooling and door down. Figures marked in days with F on first day = kind of pipe; last day, show temperature reached.

The methods shown here have been used in several cases on large and small shops, both brick and hollow ware, and in a number of instances have shown how the production on those particular yards could be increased, and later were increased.

The charts are ruled similar to co-ordinate paper, the squares being made from one quarter to one-half inch in size. This may be as the user wishes and is governed chiefly by the number of kilns and size of paper used. The scheme will prove most satisfactory by having each horizontal line used for one kiln with its number on the left, and each vertical column representing a day of the month. A chart for six kilns for the month of March would have thirty-one vertical spaces, one for each day, and preferably nine horizontal spaces, six for the kilns, one for the days of the month, and the two lower spaces for the number of kilns drawn and set each day. The latter are more essential on sewer pipe yards with kiln capacity large enough to require the setting of two or more kilns a day. See charts.

It is hardly necessary to explain the charts as they simply represent the daily operations of each kiln. "S" means kiln being set; "F", being fired; "C" cooling; "D" being drawn. Large black spots show the kiln was idle that day; small circled spots, or red spots, show idle kilns on Sundays or holidays. Many other symbols can be used to advantage, and if the squares are large enough, little notes entered. It is convenient to show the size of ware with which the kilns are set, particularly sewer pipe kilns, as this tells how long the kiln ought to burn. This is best shown in small figures the day the kiln is set or on the first day of firing. See Chart I. The last day of burning, it is well to mark in the time the kiln was finished and the temperature reached. See Chart II. In showing the firing, a good way is not to mark "F" but the number of days the kiln has been burning. When wanting to know when he can ship a lot of 24s, the man in the office can look at the chart, find the kiln that has them in and tell at a glance how many days it has been on fire. It is then easy to figure when the kiln can be drawn.

In making the charts, it is well to show Sundays by heavy ruling, red ink, or some similar method. There is some excuse for idle kilns on Sunday if the chart shows that they are idle during set-

Fig. 2.

LOG OF KILN OPERATIONS IN PAVING-BLOCK YARD

Trans. Am. Cer. Soc. Vol. XV — Fourteen Kilns, March 1913 — Riddle

Kiln No.	1	S	3	4	5	6	7	8	S	10	11	12	13	14	15	S	17	18	19	20	21	22	S	24	25	26	27	28	29	S	31	
1	S	S	S	S	F	F	F	F	F	F	F	F	F	F	F 10 PM Cone 6	C	C T	C	C D	C	C	●	◎	●	●	D	D	D	S	◎	S	1
2	D	◎	D	D	S	S	S	F	F	F	F	F_x	F	F	F	F	F	F 9 AM 6T	C	C T	C	C D	C	C	●	●	●	●	D	◎	D	$1\frac{2}{3}$
3	C	C	C	C	D	D	D	S	◎	S	S	F	1	2	3	4	5_x	6_x	7	8	9	10	11	4 AM 12 6D	C	C T	C	C	C	C	●	1
4	8	11 PM 9 5D	C	C T	C	C D	C	D	◎	D	D	S	S	S	F	1	2	3	4_x	5	6	7	8	9	10	12 PM 11 6D	C	C	C	C D	C	1
5	5	6	7	8	9	10 AM 10 6D	C	C	C	C D	C	D	D	D	S	◎	S	S	F	1	2	3	4_x	5_x	6	7	8	9	11 PM 10 6D	C	C T	1
6	1	2	3	4	5	6	7	8	11 PM 9 5D	C	C	C	C D	C	D	◎	D	D	S	S	S	F	1	2	3	4	5	6	7	8	9	1
7	S	◎	S	S	F	1	2	3_x	4	5	6	7	11 PM 8 5D	C	C T	C	C D	C	D	D	D	S	◎	S	S	F	1	2	3	4	5	1
8	D	◎	D	D	S	S	S	F	1	2	3_x	4	5	6	12 M 7 6D	C	C T	C	C D	C	C	D	◎	D	D	S	S	S	F	1	2	2
9	C	C	●	●	D	D	D	S	◎	S	S	F	1	2	3_x	4	5	6	7	C	C	C	C D	C	C	D	D	D	S	◎	S	2
10	C	C T	C	C D	C	●	●	D	◎	D	D	S	S	S	F	1	2	3_x	4	5	6	7	10 AM 8 6D	C	C	C	C D	C	D	◎	D	$1\frac{2}{3}$
11	11	4 AM 12 7D	C	C T	C	C D	C	C	◎	●	●	D	D	D	S	◎	S	S	F	1	2	3_x	4	5	6	7	10 AM 8 5D	C	C T	C	C D	1
12	6	7	8	9	3 PM 10 6D	C	C T	C	C D	C	C	●	●	●	D	◎	D	D	S	S	S	F	1	2_x	x_3	4	5	6	9 AM 7 6D	C	C T	1
13	4_x	5	6	7	8	9	10	4 AM 11 7D	C	C	C T	C	C D	C	●	◎	●	●	D	D	D	S	◎	S	S	F	1	2	3	4_x	5	1
14	F	1	2	3	4_x	5	6	7	8	9	5 PM 10 6D	C	C	C T	C	C D	C	●	●	●	●	D	◎	D	D	S	S	S	F	1	2	1
Setting Crew	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	
Drawg Crew	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	
Total Kilns																																16

Idle days on kilns 24. Note that this is sufficient time for a rotation, i.e, 17 kilns could have been drawn instead of 16 if properly handled.

Fig. 3.

IDEAL AND ACTUAL OPERATIONS IN A DRY-PRESS BRICKYARD

Trans. Am. Cer. Soc. Vol. XV — March, 1913 — Riddle

This chart filled in at first of month as a desired schedule of operation

Kiln	1	S 2	3	4	5	6	7	8	S 9	10	11	12	13	14	15	S 16	17	18	19	20	21	22	S 23	24	25	26	27	28	29	S 30	31	
1	S	◉	S	S	S	S	S	S½	F¹	F²	F³	F⁴	F⁵	F⁶	F⁷	F⁸	F⁹	F¹⁰	C	C	C	C	C	C	D	D	D	D	D	◉	D	1
2	D	◉	D	D	D	D	D	S½	◉	S	S	S	S	S	S	F¹	F²	F³	F⁴	F⁵	F⁶	F⁷	F⁸	F⁹	F¹⁰	C	C	C	C	C	C	1
3	F¹⁰	C	C	C	C	C	C	D	◉	D	D	D	D	D	●	◉	S	S	S	S	S	S	◉	S½	F¹	F²	F³	F⁴	F⁵	F⁶	F⁷	1
4	F³	F⁴	F⁵	F⁶	F⁷	F⁸	F⁹	F¹⁰	C	C	C	C	C	C	D	◉	D	D	D	D	D	○	◉	S½	S	S	S	S	S	◉	S	1
Total Kilns																																4

Chart of actual operations

Kiln	1	S 2	3	4	5	6	7	8	S 9	10	11	12	13	14	15	S 16	17	18	19	20	21	22	S 23	24	25	26	27	28	29	S 30	31	
1	S	◉	S	S	S	S	S	S½	F¹	F²	F³	F⁴	F⁵	F⁸	F⁷	F⁸	F⁹	F¹⁰	F¹¹	C	C	C	C	C	C	D	D	D	D	◉	D	1
2	D	◉	D	D	D	D	D	D	Repair	S	S	S	Press Brkn		S	◉	S	S½	F¹	F²	F³	F⁴	F⁵	F⁶	F⁷	F⁸	F⁹	F¹⁰	C	C	C	1
3	F¹⁰	F¹¹	C	C	C	C	C	C	◉	D	D	D	D	D	D	◉	●	S½	S	S	S	S	◉	S	S	F¹	F²	F³	F⁴	F⁵	F⁶	1
4	F³	F⁴	F⁵	F⁶	F⁷	F⁸	F⁹	F¹⁰	F¹¹	C	C	C	C	C	C	◉	D	D	D	D	D	D	◉	●	●	S	S	S	S	◉	S	1
Total Kilns																																4

ting or drawing on a yard where it takes a couple of days for each, as Chart III, but with sewer pipe this can be lessened considerably. See Chart I on the 9th and 15th.

Chart I represents operations on a fourteen kiln sewer pipe yard and shows a very good month's run, but it is doubtful if many yards could operate as this shows. Note the daily drawing and setting columns. They show, for the most part, that every other day two kilns were set and that two were drawn on each alternate day. This would mean that a shifting crew would have to draw a kiln one day and set another the next day. See the 12th. It shows two kilns drawn and two set while there was only one of each on the 10th.

Chart II represents a fourteen kiln, paving block plant, kiln rotation. Note that there are twenty-four idle week days and twenty-three idle Sundays. One of these kilns can be turned over in about twenty-five days, so that there could be another kiln of ware turned out, provided the shop capacity was great enough. A glance at the daily drawing and setting record shows that the crews worked every day so that it would be necessary to help these crews.

Chart III shows operations of the kilns on a four kiln, face brick, yard. The upper part shows a chart made at the first of the month and filled in for the entire month as the manager would like the burning to go if possible. The lower chart shows the actual operations on the yard as entered each day. This method is useful, for it helps every one to look ahead and gives the burner something to try to live up to. In starting each month, it is necessary to enter the record for the first day as the kilns actually are.

If the chart is used with no desire to improve operations, but merely as a record, it will be found very useful and easy to keep, and the entire month's work can be shown in a small note book. If records such as those described are kept for several months on a poorly operated yard, it is surprising what an improvement can be made.

THE EFFECT OF ZINC IN UNDERGLAZE COLORS CONTAINING CHROMIUM

BY FORREST K. PENCE, OHIO STATE UNIVERSITY

The subject of this note was suggested by a statement by Heubach[1] in which the inference is made that the green developed by chromium in an underglaze stain is not destroyed by the presence of zinc in the stain, as it is by zinc in the glaze.

All stains were thoroughly mixed by grinding dry in a ball mill.

The first series made consisted of zinc oxide and chromium oxide alone, the effect of any other material being thus eliminated. The stains of this series were calcined at cone 9. The compositions and results are indicated in Table I.

TABLE I—STAINS

STAIN NO.	ZnO EQUIV.	Cr_2C_3 EQUIV.	ZnO PARTS	Cr_2C_3 PARTS	COLORS OF FINELY POWDERED STAIN
1	1.0	4.0	81	608	Dark green in 1.
2	1.0	3.0	81	456	Changing gradually to light green with brown tint in 5.
3	4.0	7.0	81	266	
4	2.0	3.0	81	228	
5	4.0	5.0	81	190	
6	1.0	1.0	81	152	Light brownish green tending to gray.
7	4.0	3.0	81	116	Dark gray or light chocolate brown.
8	2.0	1.0	81	76	Color very similar to 7.
9	4.0	1.0	81	38	Color very similar to 7.

It is seen that the influence of zinc is early asserted, and at a molecular ratio of 4 ZnO to 3 Cr_2O_3, the green is entirely overcome. A further increase in ZnO does not change the quality of the color.

It was desired to construct a series which would contain the various elements which might normally enter into the composition of an underglaze stain. The series selected was calcined at cone 2. The series and results are given in Table II.

It is noted in the series that the green color disappears at a ratio of approximately 20 ZnO to 1.0 Cr_2O_3. This ratio is seen to

[1] *Trans. A. C. S.*, vol. xiv, p. 429.

TABLE II—GLAZES

STAIN NO.	EQUIVALENTS					PARTS					COLOR OF FINELY POWDERED STAIN
	ZnO	Cr_2O_3	Al_2O_3	SiO_2	B_2O_3	Zinc Oxide	Chromium Oxide	Calcined Aluminum Oxide	Flint	Boracic Acid	
10		1.0	0.8	2.0	0.75		152	81.5	120	93	Green, medium shade.
11	0.5	1.0	0.8	2.0	0.75	40.5	152	81.5	120	93	Medium green, slight brown tint.
12	1.0	1.0	0.8	2.0	0.75	81.0	152	81.5	120	93	Similar to 11 except lighter in shade.
13	1.5	1.0	0.8	2.0	0.75	121.5	152	81.5	120	93	Gray, with tint of green.
14	2.0	1.0	0.8	2.0	0.75	162.0	152	81.5	120	93	Gray, with decided tint of pink.
15	2.5	1.0	0.8	2.0	0.75	202.5	152	81.5	120	93	Decided pink, of grayish quality.
16	3.0	1.0	0.8	2.0	0.75	243.0	152	81.5	120	93	Similar to 15 only of stronger or more pronounced shade.
17	3.5	1.0	0.8	2.0	0.75	283.5	152	81.5	120	93	Similar to 16 only strength of color is somewhat increased.
18	4.0	1.0	0.8	2.0	0.75	324.0	152	81.5	120	93	Similar to 18 with strength of color somewhat reduced.

be somewhat greater than that required in the preceding series, as would be expected from the influence of other elements present. The nature of the color produced is quite different tending to brown in the former series and grayish pink in the latter. There was no apparent tendency toward the tan brown often seen in glazes which contain zinc and chromium and which is set forth in Bryan's study.[2] The zinc appears to be as active in its effect in the stain as it is in the glaze. In fact the green color of the stain is overcome with a relatively less proportion of ZnO to Cr_2O_3 than is required to bring about this result in the glaze. However, a much higher equivalent of Cr_2O_3 is present in the series of stains given than was used in Bryan's series of glazes.

[2] *Trans. A. C. S.*, vol. x.

This study is not purported to be exhaustive, but some observations may be made:

1. It is demonstrated that the color effect of zinc upon chromium in underglaze stains is similar to the action of the same in glazes.

2. The tint or quality of color obtained is determined by the composition of the stain. This indicates that the change in color obtained is the result of the formation of one or more compounds into which zinc and chromium enter and that the different compounds have their characteristic tints.

DISCUSSION

Prof. Parmelee: I would like to ask Professor Pence whether he is familiar with the observations made by Dr. Petrick, a few years ago in regard to obtaining pink by the use of chromium and zinc?

Prof. Pence: I have seen the references to pink obtained by chromium in connection with alumina.

Mr. Heubach: In regard to that chromium-zinc pink I would like to say I produced that same color, but I had a small amount of chromium, it was something similar to the chromium-aluminum pink.

Prof. Parmelee: Dr. Petrick drew attention to that to illustrate his point that the pink was due to physical causes rather than chemical combinations.

Mr. Watts: It was either last year or year before that I cited a number of chromium-alumina colors, and I recollect that I included in those tests and reported that I got my best pinks by a small addition of zinc to the chrome-alumina colors. Those were merely the powders used as under-glaze colors.

NOTES SUBMITTED AFTER READING THE PAPER

Mr. Heubach: I am glad that Professor Pence took up this work, and I hope he will carry it one step further by using these stains as underglaze colors and as coloring matter in glazes. I am inclined to believe that he will then get a somewhat larger range of green colors.

The statement which I made last year about the influence of zinc oxide on chromium stains was not very clear. It was not meant to refer to the color of the stains as such, but rather to the color which these stains will produce in and under the glaze. My experience with zinc in connection with chromium is rather limited, otherwise I would have used more definite terms in my statement than I did.

Some time ago, I tried to produce the typical zinc-chromium browns, in glazes which did not contain zinc, by the use of chromium-zinc stains. I simply added about five per cent of these stains to the glaze. I did not go to the extremes however, and that may account for the fact that the resulting glazes were distinctly green. Unfortunately, I did not preserve the records of these experiments; and, therefore, I cannot give any figures.

At the time, I was surprised at the results; but it is quite likely that these stains were not stable and that the glaze dissolved the zinc. The resulting glaze would then contain zinc; but unless a large amount of stain was used, the zinc content of the glaze would not be high enough to affect the green color. This is an inference of which I am not certain; and I should, therefore, like to see Professor Pence cover this point in his investigation. My experiments were made with glassy glazes and with barium mats, neither of them containing any zinc.

I have never done any systematic work along this line, but I have used zinc oxide in stains at different times. One stain, which I used quite extensively in terra cotta glazes, contains zinc and chromium in the proportion 2 ZnO to 1 Cr_2O_3. The color of this stain is a clean green, it gives a good green under the glaze as well as in the glaze. This shows that the ratio of zinc to chromium in a stain does not in itself justify any conclusions, if other materials are present. The nature as well as the amount of the other materials has a decided influence on the color. For instance, Professor Pence's stain No. 14, which comes closest to the stain referred to above, as far as the ratio of ZnO and Cr_2O_3 is concerned, contains approximately 25 per cent of zinc oxide and 25 per cent of chromium oxide with 50 per cent other materials. My stain contains 37 per cent each of zinc and chromium and only 26 per cent other materals. His stain is gray with a pink tint, my stain is distinctly green.

The same applies to glazes. In Mr. Bryan's study,[4] we find a ratio of 5 ZnO : 1 Cr_2O_3 in his glazes No. 22 and No. 34, yet No. 22 is green and No. 34 is brown. Again, if we compare his glazes No. 31 and No. 34, No. 34 with a ratio of 5 ZnO : 1 Cr_2O_3 is brown, while No. 31 with a ratio of 20 ZnO : 1 Cr_2O_3 is green.

I stated last year that I produced these same brown tints in alumina mats. Professor Pence, on the other hand, states that he was able to produce green colors in alumina mats. I do not doubt his statement in the least. This is where another very important factor comes in—the kiln treatment. Undoubtedly, Professor Pence worked under different conditions; and I made the mistake, which, by the way, is quite common in publications of this kind, of not stating clearly the conditions under which I had obtained my results. It may be well, perhaps, to state now that the glazes[5] to which I was referring were burned in a 120 hour's burn and cooled in approximately 120 hours.

Mr. Humphrey called attention[6] to the importance of the duration of the burn, and I will cite an example later in which the cooling brought out a change in color.

As another illustration that alumina does produce brown colors in glazes under certain conditions, I will cite an experiment with a glossy glaze. I produced a fritted glaze one time which gave very nice green colors with chromium stains, but it was too fusible. In order to make it more refractory, I increased the alumina and the silica gradually, keeping the RO constant. All went well up to a certain point but from that point on, the greens changed rapidly to browns. It may be stated that chromium oxide, used as such, changed to brown much earlier, i.e., at a lower alumina content, than the chromium stains did. The glazes did not contain any zink. Since the only variation in this case was with the silica and alumina and since silica, as far as I know, does not affect the chromium colors, we must conclude that the alumina is responsible for the change of color.

Chromium stains will not give green colors in vitrified clay

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[4] *Trans. A. C. S.*, vol. x, p. 127.
[5] *Trans. A. C. S.*, vol. xiv, p. 428.
[6] *Trans. A. C. S.*, vol. x, p. 132.

bodies, unless they are burnt under reducing conditions, which also indicates the effect of alumina on chromium colors.[7]

I will also state that I noticed a similar influence on chromium colors in glazes high in magnesia, although in this case the effect is not so pronounced as in the case of zinc or alumina. This effect of magnesia is shown in Dr. Buttner's article on "The Role of Chromium Trioxide in Glazes."[8] In his experiments he gradually replaced lead by zinc and the alkaline earths; and while the color changes from different shades of reds directly to green with lime and barium, the zinc changed the color to decided browns, and magnesia also gives brownish tints.

The fact that I found zinc, alumina, and magnesia very serviceable in the production of high temperature pinks, leads me to believe that these pinks and the various chromium browns are due to the same cause.

Although there are a number of phenomena which seem to justify the assumption that we are dealing with compounds into which chromium and either zinc, alumina or magnesia enter, I am inclined to take Mr. Bryan's view, i.e. that it is merely a question of oxidation. I will cite a few experiments which seem to support this view.

I had some rather interesting experiences with chromium colors which were burnt under reducing conditions. A high-temperature alumina mat, with a small addition of chromium oxide, applied to a flat tile and burned under strongly reducing conditions, gave a very nice bronze-green. The same glaze, applied to ornamental pieces and burned under exactly the same conditions, came out the same green in the lower portions, while the raised parts showed a delicate brown. This, by the way, gives a very good imitation of tarnished or weathered bronze. We might assume the formation of some chrome-alumina compound in this case; but my theory is oxidation on cooling, for why did the brown not form on the flat tile or on the lower parts of the ornament?

Another experiment will illustrate this oxidation on cooling more clearly. When experimenting with high-temperature (cone

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[7] Compare this statement with Purdy, *Trans. A. C. S.*, vol. xiv, p. 267.

[8] *Sprechsaal*, 1911, No. 46.

12 to 14) underglaze colors on feldspar porcelain, I used a glaze of the Seger-formula type and of no special merit. In the course of the investigation, I used a mixture of 85 percent of this glaze and 15 percent of chromium oxide as an underglaze color. The same base glaze was applied over it, and the trial burned in a commercial porcelain kiln under strongly reducing conditions. The result was a nice chromium green underglaze. At about the same time, a few pieces of porcelain came to my attention which carried some decorations in a beautiful tan-brown, which looked as tender as underglaze colors on porcelain usually do. Knowing from experience how difficult it was to produce a good brown under the glaze at porcelain heat, I began to speculate how this color was produced. I remembered my observation of the brown on the raised parts of the pieces with the cone 9 alumina mat, and it occurred to me that this color might have been applied over the glaze and then the piece had been refired at porcelain glost heat.

I used the same mixture of 15 chromium oxide and 85 glaze, applied it on a burnt piece which carried the same glaze as that used in the color mixture, and burnt it in a porcelain kiln to cone 13 under the same reducing conditions as the green underglaze color had gone through. The result was a beautiful tan-brown. The color had sunk into the glaze and resembled an underglaze color in appearance.

Now, in this case, we have a glaze which contains no zinc and no excessive amount of either alumina or magnesia. The burning conditions were exactly the same in both cases, and yet when applied over the glaze it gives a tan-brown. With no difference in composition and no difference in burning, the color change must be brought about during the cooling process. During the burning, oxidation is prevented in either case on account of the reducing conditions. During the cooling, the stain under the glaze is protected from oxidation by the glaze and a green color results, but the overglaze color is oxidized, producing a tan brown.

I report these experiments merely in an effort to throw some light on the problems involved. They are by no means conclusive, however, and there are quite a number of points which need further investigation before we may hope to understand these phenomena thoroughly.

HYDROUS SILICATES FORMED UNDER STEAM PRESSURE

BY S. E. BARRINGER, SCHENECTADY, N. Y.

INTRODUCTION

Some eight or nine years ago the writer carried on an extended investigation towards determining the value of hydrous silicates for purposes of electrical insulation. Silicates of various bases were investigated and also the use of various steam pressures, impregnation processes, varying degrees of fineness of material, etc. Notes covering some of this work are now presented to the Society with the hope that they may be of general interest to ceramic engineers.

Experiments with mixtures of hydrous calcium silicates developed the compound described in U. S. Patent No. 1,009,630, granted to the author, November 21, 1911.

For the best results for certain purposes of electrical insulation, it was found that a high percentage of silicate was desirable in the finished product and also that an inert fibrous material, as asbestos, was necessary for purposes of mechanical strength. Such a compound may be secured by the following mixture:

30	Parts	Slaked Lime
45	"	Flint, or Silex
25	"	Asbestos Fiber
100	Parts.	

These ingredients are mixed with the aid of suitable apparatus, the prepared compound compressed to the desired form in steel dies in hydraulic presses, lever presses, etc., and the pressed pieces are then dried, subjected to steam pressure, again dried and are then ready for use. Some of the many designs into which such a compound may be formed are shown in the accompanying cut, Figure 1.

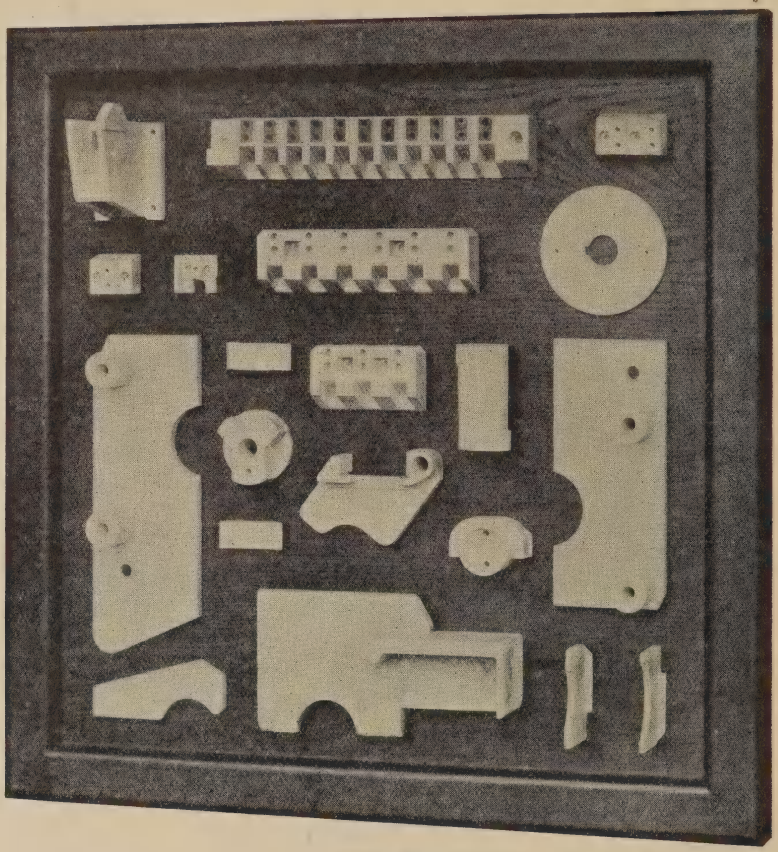

Fig. I

EFFECT OF VARYING STEAM PRESSURE

While developing this material an investigation of the effect of varying steam pressure was made with results as shown in the following paragraph.

To note the effect of varying steam pressure, freshly pressed, rectangular pieces, 3 in. by $1\frac{9}{16}$ in. by $\frac{3}{8}$ in. of the above compound were dried at 120°C. over a hot plate, then placed in an autoclave and subjected to a six-hour treatment under different steam pressures. After being hardened the pieces were dried over night on a hot plate at 200°C. The results of the test are tabulated in

Table 1, three samples being used for determination of disruptive strength and transverse strength and one sample for absorption.

TABLE 1

NUMBER	STEAM PRESSURE LBS. PER SQ. INCH	TEMPERATURE		PUNCTURING VOLTAGE	TRANSVERSE BREAKING LOAD	AVERAGE	ABSORPTION AT 24 HOURS
		Deg. F.	Deg. C.		*lbs.*		
91105	105	340.7	171.5	16200	210		20.8
				22400*	210		
				22200*	210	210	
91120	120	349.7	176.5	17200	230		20.8
				19400	220		
				22200	223	224	
91135	135	358.0	181.0	21900*	185		20.0
				22200*	246		
				23000*	259	230	
91150	150	365.0	185.0	22700*	230		20.9
				23800*	216		
				23300	225	224	
91175	175	376.7	191.5	22600*	250		21.4
				23000*	200		
				21900*	238	229	
91200	200	387.5	197.5	23500*	237		22.1
				23500	245		
				23800	236	239	
91225	225	397.4	203.0	22700*	240		21.4
				23800*	190		
				24500*	207	212	
91255	255	407.3	208.5	22000*	215		22.1
				23000*	230		
				22500*	220	222	
91285	285	417.2	214.0	22700*	235		22.9
				23300*	239		
				21600*	237	237	
91335	335	431.6	222.0	22200*	235		22.9
				23300*	239		
				21600*	237	237	
9160–S (superheated steam)	60	432.1	222.25	12600	65		
				14800	82		
				14100	75	74	

* Arced over

The puncturing voltage was made on $\frac{3}{8}$ inch thickness and determined between terminals 0.100 inch in diameter. The transverse strength was made with supports $2\frac{1}{2}$ inches apart, load applied in centre, breaking area $\frac{3}{8}$ in. by $1\frac{9}{16}$ in. The absorption was determined by weighing dry, weighing after soaking 24 hours and noting percentage of gain in weight.

From these tests, it is evident that the same results are not obtainable by using low pressure and steam superheated to the temperature corresponding to 335 lbs. pressure as with 335 lbs. pressure, or even with 105 lbs. pressure. Even could superheated steam be used its economy is questionable.

A uniformly good product in all respects appears to be obtained at 135 lbs. per square inch, but this seems to be the dividing line below which poor results are likely to occur, and above which the products are uniformly strong and of good insulating value. To allow a margin of safety, in order to always be sure of a properly hardened product, a pressure of at least 150 lbs. per square inch, has been set as the working pressure for steam hardened products made in the factory.

EXPERIMENTS TO ASCERTAIN THE INFLUENCE OF STEAM PRESSURE UPON OTHER BASES THAN LIME

A general investigation was made with a view to ascertaining whether there were other oxides or hydrates than those of lime, which could be made to combine with silica under the influence of steam pressure.

Mixtures of bauxite and flint and of limonite and flint failed to give any indication of chemical combination.

A mixture of 40 parts brucite and 60 parts flint hardened practically to the extent of the lime-silica combination and a hydrous magnesium silicate had probably been formed. The product was hard and dense.

A mixture of manganite and flint likewise gave a hard, stony product.

An attempt was made to obtain an iron silicate by using a mixture of precipitated ferric hydrate and flint. The flint, 45 grams, and the same quantity of ferric chloride, were ground together in an iron mortar to 30-mesh. To this yellow powder was added

45 cc. of ammonium hydroxide, which precipitated the iron, giving a dark red paste. This paste was allowed to stand one hour, when 20 grams of asbestos were added, and then molded into small briquettes and dried over a hot plate. The mixture did not dry very quickly, the salts present seeming to retain water. The briquettes were then placed in an autoclave and treated to steam pressure at 200 lbs. per square inch for six hours. After this treatment, there was no signs of combination, the briquettes having lost all shape and the mass having no hardness.

The following mixtures were made by mixing the ingredients dry, moistening, pressing, drying and subjecting to 150 lbs. steam pressure for four hours:

	44	*45*	*46*
Barium Hydrate (C. P.)	36	...	...
Barium Monoxide (Anhydr. Pure)		36	...
Chromium Hydrate (Merck)		...	36
Flint (99.3 SiO_2)	54	54	54
Asbestos Fiber	10	10	10
	100	100	100

Nos. 44 and 45 showed hardness in spots as though there had been partial combination. No. 46 showed no change over the dried condition before steaming.

The possibility of securing zinc and strontium silicates was then tried and also the possibility of securing a silicate from some oxide of hydrate which would give a colored silicate instead of the light colored ones, which had been obtained from lime and magnesia and which might also be expected from zinc and strontium. This series of tests was as follows; the amount of asbestos being kept low to facilitate the hand preparation:

33.	Zinc oxide	36	40.	Flint	60
	Flint	54		Cupric oxide (Blk)	40
	S. W. Asbestos	10			100
		100			
34.	Strontium oxide	36	41.	Flint	60
	Flint	54		Cuprous oxide (red)	40
	S. W. Asbestos	10			100
		100			
39.	Flint	60	42.	Flint	60
	Litharge	40		Nickel oxide (green)	40
		100			100

For these compositions the dry ingredients were mixed in a bottle mixer for several hours, dampened and pressed into cylindrical pieces about 1 inch in diameter by 1 inch long, with a $\frac{1}{4}$-inch hole through the center. On dampening 34 for pressing, the mixture grew quite warm, no doubt resulting from the hydration of the strontium oxide. Number 34 pressed slightly harder than 33. The briquettes were dried over a hot plate five hours, treated in the autoclave for six hours at 200 to 225 lbs. per square inch (200° C).

In 40, 41 and 42, evidently there had been no reaction or combination, the resulting pieces being soft and easily broken apart between the fingers.

Number 34 cracked. Not very hard and easily broken in the fingers.

Number 33 a hard, stone-like product, gray in color. Combination undoubtedly effected.

Number 39. In the case of litharge a very hard stone-like product had been formed and the color had changed from the ordinary buff color, given the pieces before hardening by the litharge, to a stone-gray color not unlike the lime and zinc silicates.

COMPARISON OF HYDROUS-SILICATES OF LIME, MAGNESIA, ZINC AND LEAD

To ascertain what marked differences there might be in these silicates, which it had been demonstrated could be formed by steam pressure, the following series of mixtures was made:

	36	*37*	*38*	*43*
$Ca(OH)_2$.....	36	...	.....	...
MgO (heavy).....	...	36	...(80-mesh)	...
ZnO.....	...	...	36	...
SiO_2.....	54	54	54(150-mesh)	54
S. W. Asbestos.....	10	10	10	10
PbO.....	...	...	...	36(80-mesh)
	100	100	100	100

The mixtures were weighed out dry (using 1000 gm. batches) and rolled in a stoneware jar mixer, with cylindrical oak blocks, for three hours, insuring a very intimate mixture of the ingredients.

The mixtures were then moistened to the proper consistency for pressing, an effort being made to get as nearly the same consistency as possible. In 38 the lumps were more difficult to break up than in 36, 37 and 43. The last were easily pulverized. After dampening and mixing by hand, the mixtures were again put in a jar mixer and rolled for half an hour, which broke up the lumps fairly well. The weight of each batch after wetting and mixing was as follows:

	Grams		*Grams*
36	1175	38	1152
37	1205	43	1120

From this it would be noted that the lighter bases, giving the more bulky masses, require a little more water for bringing to standard consistency. The prepared mixtures were then pressed into small rectangular pieces 3 in. by $1\frac{1}{2}$ in. by $\frac{3}{8}$ in. Nos. 36 and 37 required about equal weight to give the proper density, while a little greater weight was required with 38. The approximate ratio of weights required to press the pieces was as follows:

	Grams
36 and 37	48
38	61
43	80

The pieces were dried in an electric oven, raising the heat to about 85°C. and allowing the pieces to remain in the oven over night. Some of the pieces were weighed when thoroughly dried, so that upon obtaining the weight after the compounds had been hardened and dried, the gain or loss in weight, due to the chemical reaction in the hardening cylinder, could be noted. A preliminary test of 38 was made at 185 to 190°C. for two and a half hours, upon which treatment the compound partially hardened. It was not a very strong product, but evidently reaction had partially taken place.

The dried pieces were placed in an autoclave and treated at 185 to 187°C. (150 to 160 lbs. per sq. in.) for six hours. The temperature was held at almost exactly 187°C. during four hours of the run. The pieces were cooled in the autoclave over night and removed in the morning. Nos. 36, 38 and 43 were hard, solid,

stone-like masses, gray in color. No. 37 was hard, but badly warped and cracked, and the color was slightly pinkish.[1]

The hardened pieces were dried in an electric oven for six hours at 260 to 280°C. No. 38 had a harder ring when struck than No. 36. To No. 37 there was no ring; mixture was rather punky.

By this very crude method of weighing the dried pieces before hardening, hardening as described, then drying and again weighing, the amount of water taken into combination was roughly ascertained, and upon the basis of such tests the silicates formed in the various instances were computed to be approximately as follows:

$$CaO\ SiO_2\ 0.54\ H_2O$$
$$MgO\ SiO_2\ 0.45\ H_2O$$
$$ZnO\ SiO_2\ 0.05\ H_2O$$

The litharge-flint mixture showed no gain, but on the other hand a slight loss as shown below:

	Grams
Weight dry, before hardening	72,746
Weight after being hardened and dried	72,593
	0.153

Upon samples of the various mixtures tests were made for mechanical strength, disruptive voltage and absorption. The results are tabulated in Table 2.

Transverse tests were made with supports $2\frac{1}{2}$ inches apart and the load applied in the center.

From this data it is seen that the lime silicate has the highest disruptive strength and is thus to be preferred for electrical insulating purposes. The highest mechanical strength also falls to the calcium silicate. The lowest absorption is shown by the magnesium silicate, with zinc and lead silicates both low as compared with the lime compound.

The tests were reliable as far as the calcium, zinc and lead silicates were concerned, since very satisfactory, stone-like products were obtained, but the results upon the magnesium silicate are somewhat open to question through the presence of defects in the finished piece. Subsequently it was determined that this was

[1] The warping and cracking of the magnesia compound was probably due to hydration of the oxide in the cylinder and consequent expansion and disruption of the mass.

TABLE 2

NO.	DIMENSIONS OF SECTION	TRANSVERSE BREAKING LOAD IN LBS.	PUNCTURING VOLTAGE	ABSORPTION PERCENT
36-A	0.374 by 1.525	145	22300	
			20100	
36-B	0.380 by 1.530	115	24500	
			22900	
36-C	0.378 by 1.524	170	21200	
			20700	
36-D	0.373 by 1.526	117	19500	
			20100	
(Average)				
36	0.376 by 1.526	137	21412	28.7
37-A	0.373 by 1.533	129	14200	
			10300	
37-B	0.368 by 1.53	105	10900	
			11400	
37-C	0.368 by 1.53	90	12000	
			13100	
37-D	0.370 by 1.53	130	9200	
			10900	
(Average)				
37	0.369 by 1.53	113.5	11500	7.5
38-A	0.370 by 1.519	70	12000	
			13600	
38-B	0.370 by 1.521	93	13600	
			13100	
38-C	0.369 by 1.521	86	13600	
			14700	
38-D	0.370 by 1.521	92	16400	
(Average)				
38	0.370 by 1.521	85.25	13962	13.6
43-A	0.408 by 1.56	115	13000	
			16200	
43-B	0.399 by 1.56	135	16000	
			17800	
43-C	0.411 by 1.57	108	17200	
			13900	
43-D	0.403 by 1.57	140	15200	
			18600	
(Average)				
43	0.405 by 1.565	124.5	17237	12.5

due to hydration of magnesia during the hardening. To insure fully hydrated material it was found necessary to treat the magnesia or magnesium hydrate in the steam cylinder for several hours. This preliminary treatment or exposure to steam pressure gives a thoroughly hydrated material from which perfect pieces may be obtained.

The absence of gain in weight shown in the lead silicate after hardening is of interest and worth separate investigation.

USE OF ACETATES INSTEAD OF OXIDES OR HYDRATES

According to C. de la Roche, in his French patent 361886, November 4, 1905, sandstone that would be rejected in the ordinary course, owing to insufficient strength, can be hardened by

(1) Saturating with milk of lime or with a solution in acetic acid of lime, magnesia or aluminum.

(2) Subjecting to high pressure steam in an autoclave, as in the sand-lime-brick process. Where the lime, magnesia, or aluminum is added in the form of acetate, the acetic acid is expelled as soon as the pressure inside the autoclave reaches from two to three atmospheres, 115 to 120°C., with formation of true silicates. The acid dissolves in the water which condenses inside the autoclave and is recombined with lime, magnesia or aluminum, in a receptacle constructed for the purpose in the bottom of the steaming chamber.

The application of the process of substituting acetate of lime for slaked lime in the ordinary sand-lime-brick process constitutes another portion of the same invention.

For the purpose of investigating the value of acetate in this connection, as well as ferric hydrate, the following compositions were made up:

	No. 50	*No. 51*	*No. 52*	*No. 53*
Freshly pptd. $Fe(OH)_2$	36	.....	.....	.....
Pb acetate $Pb(C_2H_3O_2)_2$	.....	52.5	.....	.....
Mg " $Mg(C_2H_3O_2)_2$	.....	74.7	.....	.....
Cu " $Cu(C_2H_3O_2)_2$	.....	.....	.....	55.6
Flint	54	54	54	54
S. W. Asbestos	10	10	10	10
	100	116.5	138.7	119.6

In making these mixtures the amount of acetate was calculated which would give approximately 36 parts of the oxide. The salts were used in 60-mesh fineness. The mixtures were rolled in a jar mixer about one hour and then pressed into small cylindrical pieces. Nos. 50 and 51 pressed easily. No. 52 became sticky and was very troublesome to press, the acetate solution making the die parts very sticky and gummy after pressing several pieces. No. 53 gave no trouble in pressing. All the mixtures were air dried over night and then over hot plate, with gas turned low, for about 24 hours. They were then transferred to the autoclave, and the pressure was slowly raised to 150 to 160 lbs. per sq. in. and maintained for about 6 hours. The resulting masses were soft and swollen much beyond the original size. No. 53 had changed to a red color from the original green. All the pieces could easily be crumbled in the fingers and apparently there had been no reaction among the ingredients. The test pieces were then heated in an electric oven to 160°C., at which temperature No. 50 was unaffected, No. 51 had swollen slightly, No. 52 was distorted, puffed up, and No. 53 was apparently unaffected. Nos. 50 and 53 were still very soft, Nos. 51 and 52 were slightly hardened.

A second test was made on samples dried over hot plate about 24 hours, and in the second test the pieces were subjected to 225 lbs. per sq. in. for about $1\frac{1}{4}$ hours. The results were the same as before—none of the materials hard, but showing swelling and distortion. No. 50 was again red.

It might be that by impregnating a previously steam-hardened silicate compound with acetate of magnesia or calcium or a heavy base, as lead or zinc, then again subjecting to steam pressure, that the compound might be improved by the formation of additional silicate throughout the mass, or the formation of hydrate in the pores of the compound, rendering the mass stronger and more impervious. With this idea, pieces of the calcium silicate compound previously mentioned in these notes were soaked in concentrated solutions of lead and magnesium acetates, the compound first having been thoroughly dried. After 3 hours immersion in the warm solution and having been allowed to remain in the cold solution 45 hours, the pieces were transferred from the solu-

tions of the autoclave, together with two untreated pieces, and subjected to about 135 lbs. pressure for about 2 hours. On removal, all looked very much alike, except that those soaked in lead acetate were cracked, as from inside expansion. The samples were all dried over the hot plate. The absorption test of 24 hours gave the following results:

	Percent
Calcium Silicate, untreated	21.0
Calcium Silicate treated with Pb acetate	16.5
Calcium Silicate treated with Mg acetate	19.2

Tests were made to determine the possibility of using acetates of aluminum, calcium, and iron for the formation of silicates. For this test the following mixtures were made up, calculating acetate sufficient to give approximately 36 parts of the oxide:

	54	*55*	*56*
Aluminum acetate, Al $(C_2H_3O_2)_3$	144	...	...
Calcium acetate $Ca(C_2H_3O_2)_2$	...	101	...
Iron acetate, $Fe(C_2H_3O_2)_3$	...	...	105
Flint	54	54	54
S. W. Asbestos	10	10	10

The ingredients were weighed out, mixed dry in a ball mixer about $1\frac{1}{2}$ hours, and then pressed into small cylindrical pieces. No. 51 pressed very well, No. 52 was very sticky and quite difficult to release from the mold; No. 53 was not as sticky as No. 52, but enough so to be troublesome in molding.

One sample from each mixture was placed in the autoclave after drying over night, and subjected to 150 lbs. for about $8\frac{1}{2}$ hours. After the treatment No. 54 was broken apart. It was soft and crumbled easily in the fingers. No. 55 was swollen and spongy and very soft. In No. 56 there was no swelling or cracking, and it was not as soft as the others, but nevertheless could be easily broken in the fingers. The color of No. 56 was medium brown outside and red inside.

A second test was run on these mixtures, the pieces having air dried for about one week, by subjecting them to 200 to 225 lbs. per sq. in. for six hours. After this test it was found that 54 and 56 had retained shape, but No. 55 had swollen and was a soft, puffed-up mass. No. 54 was quite soft. While No. 56 was firm and not easily crumbled, it was far from being a hard product.

TREATMENT OF CALCIUM SILICATE-ASBESTOS COMPOUND WITH ACETATE SOLUTIONS

Pieces 3 in. by $1\frac{1}{2}$ in. by $\frac{3}{8}$ in., made of standard calcium silicate-asbestos compound, were numbered and weighed dry (having been dried five hours over steam plate), and were then soaked in acetate solutions and again steamed treated, dried and absorption tests made.

In Table 3 are given in the first column the number of the samples, in the second the solution used, in the third column the weight of the dry test piece of No. 91 compound before treating in acetate solution, in the fourth column the weight of the test piece after soaking in acetate solution for 48 hours, then subjected to steam pressure at 150 to 160 lbs. per square inch for 6 hours, then drying on hot plate for 7 hours; in the fifth column is given the weight of the test pieces which had been treated with acetate solution, steamed and dried, and then soaked in water for 64 hours; in the sixth column the gain in weight by immersion is shown; and in the seventh column the percentage of absorption.

TABLE 3 [1]

A	(untreated)	41.25	.....	51.00	9.75	23.6
B	(untreated)	40.50	.....	50.25	9.75	24.0
1	Pb acetate	41.50	44.0	52.75	8.75	19.8
2	Pb acetate	41.50	44.0	52.75	8.75	19.8
3	Al acetate	41.25	40.0	50.00	10.00	25.0
4	Al acetate	41.00	40.0	50.00	10.00	25.0
5	Ca acetate	40.00	41.0	49.75	8.75	21.3
6	Ca acetate	41.00	41.5	50.00	8.50	20.4
7	Cu acetate	41.00	41.0	50.00	9.00	21.9
8	Cu acetate	42.00	42.0	50.50	8.50	20.2
9	Mg acetate	40.00	43.25	50.00	6.75	15.6
10	Mg acetate	41.00	42.25	50.00	7.75	18.3
11	Fe acetate	42.50	41.25	50.00	8.75	21.2
12	Fe acetate	41.50	40.50	49.75	9.25	22.8

[1] For explanation of this table see text.

From the table it will be noted that with the lead and magnesium acetates there was gain in weight by the treatment of impregnating the piece with the solution, then steaming. With copper ace-

tate there was no gain, and with the acetates of iron and aluminum there was a slight loss. There was a slight gain with calcium acetate. The absorption tests showed less absorption after the treatment with lead and magnesium acetates than with the untreated samples. The absorption was higher after the treatment with aluminum acetate, and a trifle lower after treatment with the acetate of calcium, copper and iron.

The test pieces, after drying on the hot plate again for 7 hours, were sent to the testing laboratory for determination of puncturing voltage and cross breaking strength, with the result that none were found as strong or as good in insulation value as the untreated samples, as shown in Tables 4 and 5:

TABLE 4.—PUNCTURING VOLTAGE

MARK	THICKNESS	AVERAGE VOLTS PER MIL.
A	0.367	171.6
B	0.366	218.3
1	0.367	130.5
2	0.366	147.3
3	0.367	177.2
4	0.365	172.0
5	0.363	132.4
6	0.370	89.3
7	0.365	183.1
8	0.364	176.0
9	0.362	74.6
10	0.362	74.6
11	0.364	107.2
12	0.360	150.0

With reference to Tables 4 and 5, it is significant that the highest insulation is found in the pieces which showed the greatest gain in weight after the acetate treatment, as in Nos. 1 and 2 with the lead acetate, and 9 and 10 with the magnesium acetate, also in 5 and 6 with the calcium acetate. In the matter of strength, amongst the acetate treated samples there is no very substantial difference, but all the acetate treated samples are considerably weaker than the untreated samples.

From these tests, it seems evident that the treatment with

TABLE 5.—TRANSVERSE STRENGTH
Two and one-half inches between supports

MARK	DIMENSIONS OF SECTION		BREAKING LOAD IN LBS.
	Depth	Width	
	inches	inches	
A	0.368	1.507	160
B	0.369	1.508	175
1	0.367	1.510	133
2	0.367	1.512	127
3	0.367	1.509	125
4	0.365	1.511	125
5	0.365	1.510	125
6	0.366	1.510	155
7	0.367	1.507	130
8	0.368	1.510	130
9	0.363	1.510	132
10	0.362	1.508	110
11	0.364	1.508	136
12	0.362	1.508	116

acetates, as suggested by de la Roche, is of little value in bettering the properties of calcium silicate compounds, but, on the other hand, gives an inferior product in strength and insulation value, and in some cases in porosity.

THE PRODUCTION OF A PINK VITRIFIED FLOOR TILE[1]

BY RALPH HEIDINGSFELD

INTRODUCTION

The experiment about to be described is the outcome of a problem which confronted a tile company a year ago. The company for a long time had been using buff and white combinations of tiles for borders etc., but had several calls for pink and white blends. The temperature at which the tile body vitrified was cone 11, so that the problem really confronting us was the production of a pink which would not fade at high temperatures.

EXPERIMENTAL PART

FIRST SERIES

Preparation of Stains. The mixtures shown in Tables I and II were made and calcined in fire clay crucibles at cone 11, in a commercial kiln. The burn lasted eighty hours.

TABLE I

No.	52	53	54	55	56	57	58	59	60	61
Fe_2O_3	1	2	3	4	5	6	7	8	9	10
Al_2O_3	80	80	80	80	80	80	80	80	80	80
Cr_2O_3	19	18	17	16	15	14	13	12	11	10

TABLE II

No.	62	63	64	65	66	67	68	69	70	71
Fe_2O_3	1	2	3	4	5	6	7	8	9	10
Al_2O_3	90	90	90	90	90	90	90	90	90	90
Cr_2O_3	9	8	7	6	5	4	3	2	1	0

Preparation of Bodies. These mixtures were ground dry and 3 percent and 10 percent of each was mixed with the following body:

[1] Experimental work done in the Ceramic Laboratory of Rutgers College, New Brunswick, N. J.

	Percent
Golding spar	64
Golding flint	5
Clay { ½ English china	
Clay { ½ Georgia kaolin	31

This body contained 7.5 percent of mechanically mixed water, so that a 10 percent of color sample contained 10 percent of color, 82.5 per cent of body and 7.5 percent of water.

These mixtures were pressed into tile by the dry-press process and burned to cone 11, in a commercial kiln. The duration of the burn was eighty hours.

Results. The results are shown in Table III. These results are for the 10 percent of color samples, for the 3 percent proved to be too small a quantity.

TABLE III

52	53	54	55	56	57	58	59	60	61
←	———	Drab	———	to	Light	Drab	———	———	——→
62	63	64	65	66	67	68	69	70	71
Pink	Pink	←Sal	mon	———	———	Yellow to Cream			——→

No. 62 was the best pink and proved to be very satisfactory for a light shade of that color.

SECOND SERIES

Preparation of Stains and Bodies. The second part of this experiment was carried out for the purpose of darkening the colors in the preceding part and with the hope that a red might be obtained. Five percent of $Ca_3(PO_4)_2$ was added to each of the mixtures in Tables I and II, in place of an equivalent percent of Al_2O_3, as shown in Tables IV and V.

These mixtures underwent the same identical process as those preceding; and the results were the same, except that in all cases the colors were a much darker shade.

TABLE IV

No.	72	73	74	75	76	77	78	79	80	81
Fe_2O_3	1	2	3	4	5	6	7	8	9	10
Al_2O_3	75	75	75	75	75	75	75	75	75	75
$Ca_3(PO_4)_2$	5	5	5	5	5	5	5	5	5	5
Cr_2O_3	19	18	17	16	15	14	13	12	11	10

TABLE V

No.	82	83	84	85	86	87	88	89	90	91
Fe_2O_3	1	2	3	4	5	6	7	8	9	10
Al_2O_3	85	85	85	85	85	85	85	85	85	85
$Ca_3(PO_4)_2$	5	5	5	5	5	5	5	5	5	5
Cr_2O_3	9	8	7	6	5	4	3	2	1	0

Results. Number 82 was the nearest approach to a red; and when the light shown through, a ruby lustre resulted, but when one looked at it against a back ground, it was a color resembling old rose.

The mixture containing 9 percent of Cr_2O_3, 90 percent of Al_2O_3, 1 percent Fe_2O_3, seemed to be the best pink; and, as the Cr_2O_3 increased, the mixtures became darker, while a decrease of Cr_2O_3 gave lighter shades. Hence 9 percent of Cr_2O_3 seemed to be the point at which the conditions were just right for the formation of a pink.

It is very difficult to say just what part the iron plays in the formation of this pink; but it was shown that it increased the intensity of the color, because in a sample containing 10 percent Cr_2O_3 and 90 percent Al_2O_3 a pink resulted, but its intensity was not as great as the one with the 1 percent of Fe_2O_3, 9 percent of Cr_2O_3 and 90 percent of Al_2O_3

DISCUSSION WRITTEN AFTER READING THE PAPER

Mr. E. E. Rand: Mr. Heidingsfeld has taken as the basis for his stain one similar to what is known as a spinel color, which is recognized as a very suitable form for under glaze color or body stain.

The stains are very similar in composition to those produced by Mr. Watts in his investigation on the production of a pink under glaze color. He obtained a good pink from a stain of the following composition: 90.53 percent Al_2O_3, 9.47 percent Cr_2O_3. It will be noted that this is very close in composition to No. 62 (Mr. Heidingsfeld's best light pink) except in the case of iron, which is lacking in Watts' stain. By calcining the latter to cone 18 a pinkish gray powder was obtained. No. 62 was calcined to cone 11, at which temperature a pink powder probably resulted, for though the color of the stain was not given, it was presumably like that of the burned floor tile, only darker.

In this case the iron does not appear to act solely as a colorant, since in Watts' stain pink was obtained without it. Evidently the iron, though small amount, acts as flux, by means of which the color was brought about at cone 11, instead of cone 18.

From Watts' results, it would seem that the problem was not the production of a pink which would stand high temperatures since without the use of a softening flux the color did not develop below cone 18, but changed to purplish gray at cone 22.

The use of boric acid does not seem to reduce the temperature at which the pink appears. Watts obtained a pink from the following stain: 83.62 percent Al_2O_3, 9.54 Cr_2O_3, 7.04 B_2O_3 but it also was calcined to cone 18.

No. 82 (the best dark pink) is identical in composition to No. 62, except the $Ca_3(PO_4)_2$ substitution. It is difficult to determine the way in which the $Ca_3(PO_4)_2$ produces a darker shade. It probably acts as a flux and therefore brings out a dark pink at cone 11, which would have been produced without its use at a higher temperature.

As to the part played by the iron aside from its fluxing action, it is probable that it remains in the ferric form (for if the stain is burned under reducing conditions a green results, according to Watts); if present in the ferric form it would naturally intensify the pink color; and if present in the ferrous form it would tend to darken the color present.

FELDSPAR AND A DEFORMATION STUDY OF SOME FELDSPAR AND FELDSPAR-QUARTZ MIXTURES[1]

BY ARTHUR S. WATTS

ORIGIN AND CLASSIFICATION

Origin. Feldspars are alumino-silicates of alkalies and are very common minerals, being prominent constituents of most igneous rocks. As all igneous rocks have been forced to the earth's surface in a more or less molten state, cooling and crystallization have taken place under widely varying conditions, hence the size of crystals and the uniformity of crystallization vary greatly. This is of special importance in reference to feldspars since they are rarely found in the pure state, but generally are crystallized intimately with other silicates. Only when the crystallization is very coarse or the various minerals of the original magma have segregated into independent masses, is it possible to separate the feldspar in a sufficiently pure state for commercial uses.

Classification. Feldspars may be divided according to their alkali constituent into four distinct classes, viz.,

Potash feldspars, known as microcline or orthoclase, $KAlSi_3O_8$

Soda feldspar, known as albite, $NaAlSi_3O_8$

Lime feldspar, known as anorthite, $CaAl_2Si_2O_8$

Barium feldspar, known as celsian, $BaAl_2Si_2O_8$

In nature these minerals are rarely found in the pure state but generally occur as intimately crystallized masses of two or more different feldspars. Some of the feldspars apparently combine forming homogeneous crystals of definite composition while others merely occur as isomorphous mixtures.

Iddings[2] reports the following varieties as having been recognized:

Soda-orthoclase, $(KNa)AlSi_3O$:

Plagioclase or lime-soda feldspar series, $n(NaAlSi_3O_8)$ $m(CaAl_2Si_2O_8)$

Hyalophane or barium-potash feldspar, $n(KAlSi_3O_8)$ $m(BaAl_2Si_2O_8)$

[1] By permission of the Director, United States Bureau of Mines.

[2] Iddings' Rock Minerals, p. 205.

In the plagiolcase series the ratio of soda feldspar to lime feldspar may vary from $\frac{\text{(six molecules soda feldspar)}}{\text{(one molecule lime feldspar)}}$ to $\frac{\text{(one molecule soda feldspar)}}{\text{(six molecules lime feldspar)}}$ Soda-lime feldspars containing less tean 1 : 6 ratio are classified with the pure feldspar which they approach.

The hyalophane series is classified by Rosenbusch[3] as such barium-potash feldspars as contain between 7.8 and 16.4 percent BaO. Those potash-feldspars which contain barium in quantity less than 7.5 percent are called orthoclase, and those which contain barium in quantity greater than 16.4 percent are classed as celsian.

Potash Feldspars. This class of feldspar is found in nature in two forms, viz.; *microcline,* which is the chief constituent of the ordinary feldspar of commerce, and *orthoclase,* which is less frequently met with, although until recently the microcline of commerce has gone by this name. The error has however been of no industrial importance since the chemical composition of these two minerals is identical and they differ only in crystalline form and in optical properties.

Microcline, molecular formula, $K_2O–Al_2O_3–6SiO_2$; percentage chemical composition K_2O 16.9, Al_2O_3 18.4, SiO_2 64.7; specific gravity 2.54; hardness 6 to 6.5; crystal system tri-clinic. Its color is generally white, grayish yellow, yellow or any shade of red from light rose to brick color, the red color being due to finely divided iron oxide or hydroxide. It may be green (amazon stone) in transmitted light. In thin sections it is colorless. Microline has a varying content of Na_2O up to 4 percent, and of CaO which seldom exceeds 0.5 percent.

Since the microclines which are richest in Na_2O and CaO are also mechanically mixed with the largest amounts of albite and oligoclase-albite, it is not improbable that Na_2O and CaO do not belong to the true microcline molecule. As Na_2O content increases in a microcline, the specific gravity increases until with a soda content of 4 percent the specific gravity may reach 2.57.

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[3] Rosenbusch's Mikroskopische Physiographie der Mineralien and Gesteine, Vol. 1, part 2, p. 309–313.

Orthoclase varies in few respects from microcline. It crystallizes in the monoclinic system but the polysynthetic twinning characteristic of microcline may be sub-microscopic and hence not apparent. In specific gravity and color, orthoclase is identical with microcline. Crystallization, monoclinic; hardness 6.

Soda Feldspars. This class of feldspar is found in nature in two forms, viz: *albite*, the form ordinarily encountered, and *cleavelandite*, a lamellar variety of albite differing from the latter only in massive structure and having identical optical and physical properties.

The molecular formula of albite is Na_2O–Al_2O_3–$6SiO_2$. Percentage composition, Na_2O 11.8, Al_2O_3 19.4, SiO_2 68.8. Specific gravity 2.624. Hardness 6 to 6.5. Crystallization, triclinic. Color generally white although it may be reddish, greenish, bluish or gray. Cleavelandite often displays a bluish tint. In thin section it is colorless.

The Na_2O in albite may be replaced by CaO in amounts less than 3 percent CaO and retain its name. When the CaO content exceeds 3 percent, however, the mineral is classified as a lime-soda feldspar, of which there are now recognized a series of five numbers between pure albite and pure anorthite. These form the plagioclase subgroup.

Lime Feldspar. This feldspar is known as anorthite and in its pure state occurs only in one form. The molecular formula is CaO–Al_2O_3–$2SiO_2$. Percentage composition, CaO 20.1, Al_2O_3 36.62, SiO_2 43.28. Specific gravity 2.758. Hardness 6 to 6.5. Crystallization, tri-clinic. Color, white, grayish or reddish. Colorless in thin sections.

The CaO in anorthite may be replaced by Na_2O in amount less than 1.6 percent Na_2O. When the Na_2O content exceeds 1.6 percent, however, the feldspar becomes one of the plagioclase subgroup.

Barium Feldspar. This feldspar is known as celsian and in the pure state occurs only in one form. The molecular formula of celsian is BaO–Al_2O_3–$2SiO_2$. Percentage composition, BaO 41.8, Al_2O_3 27.2, SiO_2 32. Specific gravity 3.38. Hardness 6 to 6.5. Crystallization, monoclinic. Colorless, unless stained by impurities.

Complex Feldspars. Aside from these four principal feldspars, many feldspars occur which contain two basic oxides.

Anorthoclase or soda-microcline is a feldspar in which more than one-half the potash is replaced by soda.

Hyalophane is a feldspar in which a portion of the potash is replaced by barium.

Plagioclases are lime-soda feldspars, which are a group of feldspars whose members form a continuous series connecting albite and anorthite.

The above formulae represent only the pure minerals and combinations of two pure minerals. In nature one rarely finds a pure feldspar (i.e., one containing but one alkali) in large quantity and feldspars consisting of mixtures of but two pure minerals are comparatively rare. The manufacturer therefore has little use for data based upon the pure minerals except as it can be employed to bring about a better understanding of the complex feldspars with which he has to deal.

The feldspars most extensively used in the industries are the two forms of potash-feldspars, microcline and orthoclase. The chemical compositions and physical properties of these two minerals are identical and for all practical purposes they may be dealt with as one mineral, microcline, which is the form generally encountered. In commerce, the term "potash-feldspar" is used in referring to any feldspar in which potassium is the prevailing flux, and even though the proportion of potassium is so low as to make the chemical composition approach hyalophane or anorthoclase, the latter names have never been employed in the industries.

As indicated in the above list, no series of feldspars occurs in nature in which the potash is replaced by lime, and wherever a potash feldspar contains any appreciable amount of CaO, it is safe to assume that it contains an equal or greater amount of Na_2O, the two elements being introduced in one of the plagioclases, which is perthitically intergrown in the microcline.

Hyalophane is rarely encountered in commercial quantity. Barium as a constituent of feldspars is not uncommon, but rarely occurs in excess of 0.5 percent, and generally, if present, is in quantity less than 0.25 percent. A study of the action of barium in feldspars has not been attempted in connection with this investigation, since the feldspars of the district contain little or no barium. However, it is a matter of record that potash feldspars which con-

TABLE I.—FELDSPARS WITH THEIR FORMULAE AND LIMITS OF COMPOSITION[4]

NAME	FORMULA LIMITS	BaO	K_2O	Na_2O	CaO	Al_2O_3	SiO_2
Celsian	$BaAl_2Si_2O_8$	40.8				27.2	32.0
	$(BaAl_2Si_2O_8)$ 2 $(KAlSi_3O_8)$	16.5	10.1			21.9	51.5
Hyalophane	$(BaAl_2Si_2O_8)$ 2 $(KAlSi_3O_8)$	16.5	10.1			21.9	51.5
	$(BaAl_2Si_2O_8)$ 6 $(KAlSi_3O_8)$	7.5	13.8			20.0	58.7
Microcline or Orthoclase	$KAlSi_3O_8$		16.9			18.4	64.7
Anorthoclase	$(2KAlSi_3O_8)$ 3 $(NaAlSi_3O_8)$		7.0	6.9		19.0	67.1
	$(KAlSi_3O_8)$ 6 $(NaAlSi_3O_8)$		2.5	10.1		19.3	68.1
Albite	$NaAlSi_3O_8$			11:8		19.4	68.8
Oligoclase	6$(NaAlSi_3O_8)$ $(CaAl_2Si_2O_8)$			10.0	3.0	22.1	64.9
	2$(NaAlSi_3O_8)$ $(CaAl_2Si_2O_8)$.			7.7	7.0	25.4	59.9
Andesine	3$(NaAlSi_3O_8)$ 2 $(CaAl_2Si_2O_8)$			6.9	8.3	26.5	58.3
	4$(NaAlSi_3O_8)$ 3$(CaAl_2Si_2O_8)$			6.6	8.9	27.0	57.5
Labradorite	$(NaAlSi_3O_8)$ $(CaAl_2Si_2O_8)$			5.7	10.3	28.3	55.7
	$(NaAlSi_3O_8)$ 2$(CaAl_2Si_2O_8)$			3.8	13.7	31.1	51.4
Bytownite	$(NaAlSi_3O_8)$ 3$(CaAl_2Si_2O_8)$			2.8	15.3	32.5	49.4
	$(NaAlSi_3O_8)$ 6$(CaAl_2Si_2O_8)$			1.5	17.4	34.3	46.8
Anorthite	$(CaAl_2Si_2O_8)$				20.1	36.6	43.3

[4] These formulae are according to Rosenbusch (see "Mikrokopische Physiographie der Mineralien and Gesteine"). Authorities do not agree as to exact formula-limits, but the differences are negligible in most cases.

tain even a small amount of barium display a marked decrease in viscosity when fused, as compared with similar feldspars which contain no barium.

Mixtures of microcline and albite or mixtures of microcline and albite-rich members of the plagioclase series are the feldspars with which the manufacturer has to deal in using the material popularly known as "potash feldspar."

In purchasing "soda feldspar," the manufacturer never secures pure albite because deposits of pure albite do not exist in commercial size. The nearest approach to pure albite which is obtainable in commercial quantity is a feldspar high in soda content and relatively low in potash and lime content.

DEFORMATION STUDY OF POTASH FELDSPAR—SODA FELDSPAR MIXTURES

The impression prevails among users of feldspar that "soda feldspar," or albite is the softest member and "potash feldspar," or microcline is the hardest member of a feldspar series and any mixture of these two will be proportionately hard as the relative content of the two extremes, i.e., that the deformation temperature of potash-feldspar-soda-feldspar mixtures is supposed to be on a straight line with soda-feldspar as the lowest point and potash-feldspar as the highest point. A study of a large number of feldspars containing both potash and soda as fluxes indicated that this is not true, but in a study of feldspar analyses there are so many slight variables that the exact cause of any particular property is extremely difficult to locate. However, a marked tendency was noted, in that, feldspars containing a moderately high content of soda and a proportionately low content of potash, deformed at lower temperatures than did the relatively pure soda feldspars. The following analyses of feldspars arranged in the order of their deformation will indicate the point referred to:

FELDSPARS CLASSIFIED IN THE ORDER IN WHICH THEY DEFORM

	NO. 1	NO. 2	NO. 3
H_2O	0.30	0.10	0.20
SiO_2	65.40	68.75	68.18
Al_2O_3	20.70	18.56	20.12
Fe_2O_3	0.10	0.03	0.05
CaO	1.60	1.25	0.85
MgO	trace	trace	0.05
K_2O	6.00	6.85	0.66
Na_2O	6.10	4.29	9.38
	100.20	99.83	99.49

The ordinary conception would lead to the assumption that No. 3 is the most easily fusible of the three instead of the least fusible which it really is.

In order to prove the existence of a deformation eutectic between potash and soda feldspars, a series of mixtures of these two feldspars was prepared and deformation studies made.

FELDSPARS EMPLOYED	H_2O	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	BaO
Potash feldspar	0.50	64.3	19.64	0.08	trace	trace	trace	14.00	1.32	0.17
Soda feldspar	0.20	68.18	20.12	0.05	trace	0.85	0.05	0.66	9.38	....

Neither of the above feldspars are pure type, but instead both are mixtures high in the particular feldspar sought.

Unfortunately, the large feldspar deposits all contain less than the theoretical amount of alkali, although the ratio of Al_2O_3 to SiO_2 is generally very nearly correct if the free quartz present in the pegmatite is removed. This shortage of alkali is doubtless due to slight alteration of the feldspar, but no information is available pointing to the formation of products other than kaolin by the weathering of feldspar. To subdivide an ordinary feldspar into its possible mineral components by a process of calculation based upon its alkali content results in confusion, since an excess of Al_2O_3 and SiO_2 remains after all possible minerals have been

deducted. The absence of sufficient combined water makes it impossible to calculate the excess Al_2O_3 into kaolin although the Al_2O_3 must been in other than the free state since none dissolves in hydrochloric acid.

As the feldspars used in this investigation are to be divided into microcline and albite content, the ratio of K_2O to Na_2O has been chosen as the basis of division after that amount has been deducted which can be calculated as kaolin, the combined water being used as the basis of this latter calculation. The result of this subdivision is as follows:

Potash feldspar = 85 percent microcline — 11.5 albite — 3.5 kaolin.
Soda feldspar = 4.5 percent microcline — 94.0 albite — 1.5 kaolin.

The mixtures of these two feldspars used in the investigation are as follows:

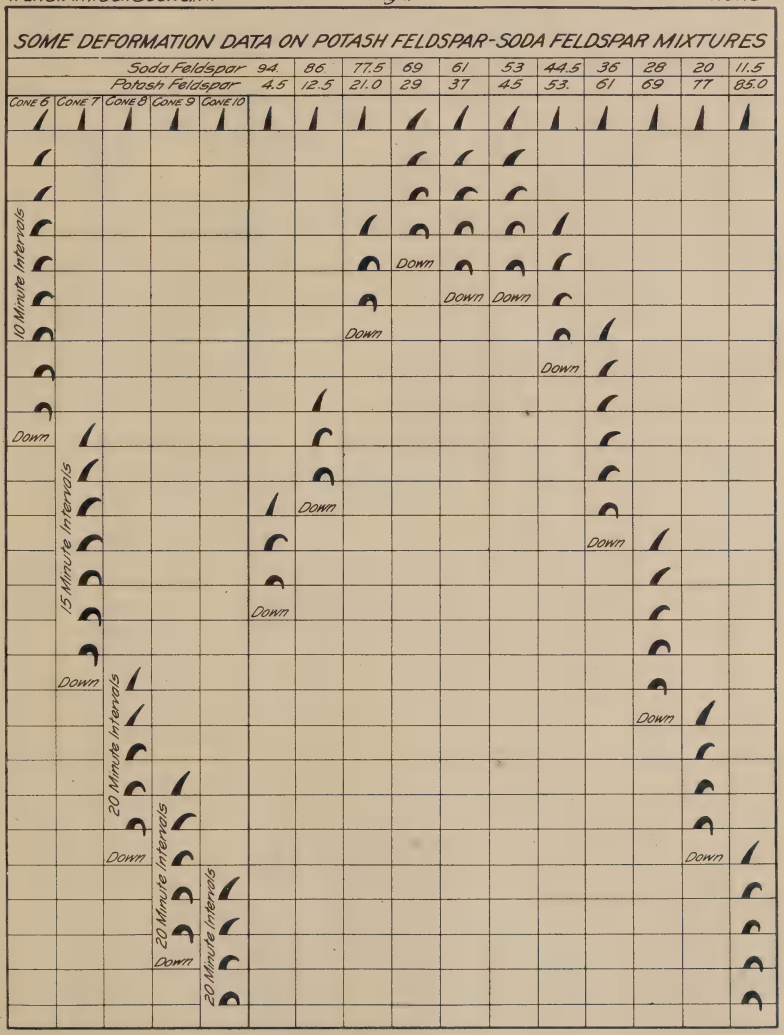
NATURAL MINERALS		APPROXIMATE NORM CONSTITUTION	
		Albite	Microcline
	Percent	*Percent*	*Percent*
Soda feldspar	100	94	4.5
Soda feldspar	90	16	12.5
Potash feldspar	10		
Soda feldspar	80	77.5	21.0
Potash feldspar	20		
Soda feldspar	70	69.0	29.0
Potash feldspar	30		
Soda feldspar	60	61.0	37.0
Potash feldspar	40		
Soda feldspar	50	53.0	45.0
Potash feldspar	50		
Soda feldspar	40	44.5	53.0
Potash feldspar	60		
Soda feldspar	30	36.0	61.0
Potash feldspar	70		
Soda feldspar	20	28.0	69.0
Potash feldspar	80		
Soda feldspar	10	20.0	77.0
Potash feldspar	90		
Potash feldspar	100	11.5	85.0

Preparation of the Mixtures for Test. These mixtures were all pulverized to pass a 200-mesh sieve, dry, and after thorough mixing in the dry state were made up into plastic masses by a small addition of dextrine solution. These plastic masses were molded into cones of the same dimensions as the standard pyrometric cones of commerce, against which they were tested. The shape and size of the standard cones for temperatures up to 1450° have been standardized and are three sided pyramids with sides $2\frac{7}{8}$ inches long and fans $\frac{9}{16}$ inch at the base and $\frac{1}{16}$ inch at the top. These standard cones melt at relatively exact temperatures under exact heating conditions. They are composed of mineral mixtures which cause them to behave under fire in a manner more or less similar to the feldspars, kaolins and quartzes in the standardization and firing of which they are chiefly used.

SEGER CONES AND THEIR DEFORMATION TEMPERATURES

Cone No.	*Deformation temperature °C.*	*Cone No.*	*Deformation temperature °C.*
1	1150	19	1510
2	70	20	30
3	90	21	50
4	1210	22	70
5	30	23	90
6	50	24	1610
7	70	25	30
8	90	26	50
9	1310	27	70
10	30	28	90
11	50	29	1710
12	70	30	30
13	90	31	50
14	1410	32	70
15	30	33	90
16	50	34	1810
17	70	35	30
18	90	36	1850

Results. Figure 1 shows graphically the order and rate of deformation of these potash feldspar-soda feldspar mixtures as compared with similar properties of standard pyrometric cones Nos. 6, 7, 8, 9 and 10. The percentage composition of the feldspar mixtures are shown along the top of the diagram. The time interval


Trans. Am. Cer. Soc. Vol. XV
Fig. 1.
Watts
SOME DEFORMATION DATA ON POTASH FELDSPAR-SODA FELDSPAR MIXTURES
Soda Feldspar 94 86 77.5 69 61 53 44.5 36 28 20 11.5
Potash Feldspar 4.5 12.5 21.0 29 37 45 53. 61 69 77 85.0
Cone 6
Cone 7
Cone 8
Cone 9
Cone 10
10 Minute Intervals
15 Minute Intervals
20 Minute Intervals
20 Minute Intervals
20 Minute Intervals
Down

and temperature increase, as indicated by deformation of the standard cones, are recorded from top to bottom along the left border.

Interpretation of the Diagram. The data here set forth is remarkably sharply defined, as regards the end numbers of this series, but unfortunately the deformation ranges of the three softest members are so nearly the same that a number of checks must be made before the eutectic can be established.

From this preliminary test it appears that a mixture of approximately 69 percent albite and 29 percent microcline begins to deform and completes the deformation process earlier than any other member of the series tested. The time required for the deformation process of this mixture is only half that required for a similar deformation process of standard cone 6, the mixture starting approximately with cone 6 and being completely deformed when cone 6 had only half deformed.

Mixtures ranging from { albite 77.5 / microcline 21.0 } to { albite 44.5 / microcline 53.0 } completely deformed before cone 6 had completed deformation The albite used in this study deformed at about the same rate as the eutectic mixture but proved to be nearly one cone harder. The mixtures containing a higher percentage of microcline than the eutectic mixture deform with decreasing rate as the microcline content increases until the potash-feldspar end of the series is reached and this has a time range of deformation equal to twice that of the albite.

Thus it is shown that high soda content does not indicate low deformation temperature. Also, the approximate proportion of soda feldspar cannot be determined from deformation studies except by a careful observation of the rate of deformation.

DEFORMATION STUDY OF FELDSPAR QUARTZ MIXTURES

One of the most confusing questions which confronts the user of feldspar is the extent to which the addition of quartz or free silica influences the pyrometric behavior of feldspar. In nature quartz is almost invariably associated with feldspar, and in most cases a complete separation of the two minerals would be very expensive if not impossible. A certain amount of free quartz is

therefore very likely to exist in any feldspar purchased in the pulverized state, unless special arrangement was made to have all quartz removed from the crude feldspar. In order that a clearer understanding may be had of the influence of quartz upon the different feldspars as regards deformation behavior, a study was made of potash feldspar-quartz mixtures and of soda feldspar-quartz mixtures.

The feldspars used were the same as in the potash feldspar-soda feldspar mixtures. These, as heretofore explained, are not pure minerals but are as nearly pure as are obtainable in commercial quantities.

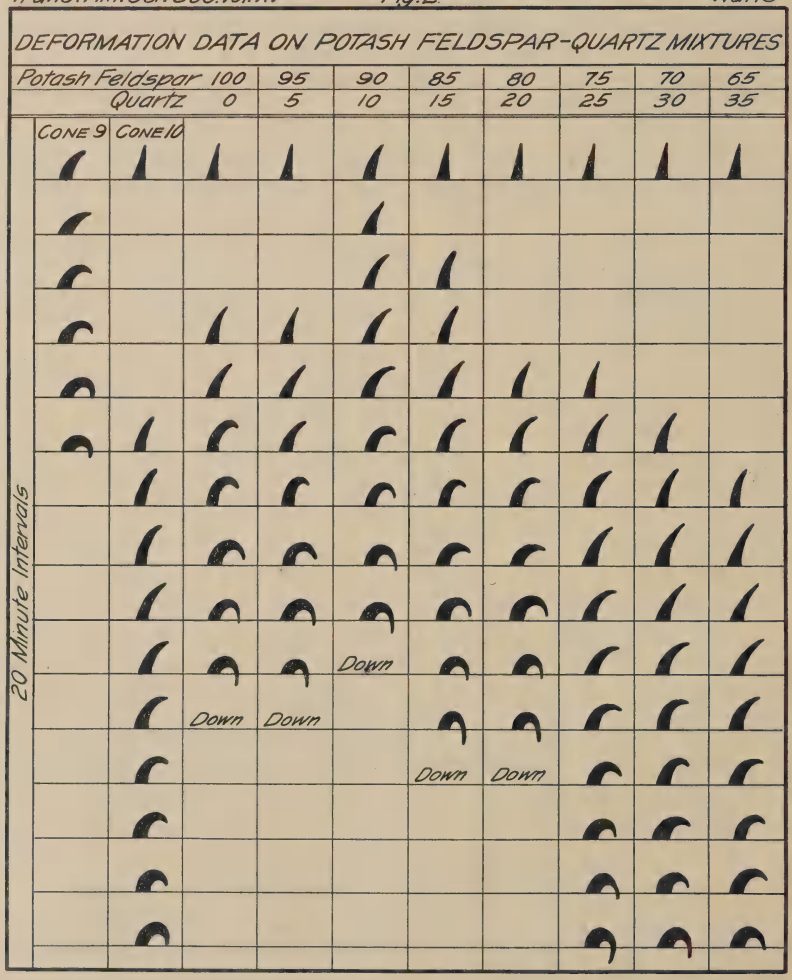
DEFORMATION STUDY OF POTASH FELDSPAR-QUARTZ MIXTURES

Potash feldspar used		*Quartz used*	
H_2O	0.50	Loss on ignition	0.11
SiO_2	64.30	SiO_2	99.18
Al_2O_3	19.64	Al_2O_3	0.00
Fe_2O_3	0.08	Fe_2O_3	0.26
TiO_2	trace	TiO_2	0.01
CaO	trace	CaO	0.01
MgO	trace	MgO	0.01
BaO	0.17		99.58
K_2O	14.00		
Na_2O	1.32		
	100.01		

The materials were ground to pass 200-mesh screen and mixed dry, in the proper proportions, after which the mixtures were made plastic by a small addition of dextrine solution. The various mixtures were molded into cones similar in shape and size to the standard pyrometric cones of commerce. The proportion of feldspar and quartz in the various mixtures are recorded across the top of Figure 2 and the intervals of time and of temperature indicated by the deformation of the standard cones are shown from top to bottom along the left margin of the diagram.

According to the data here set forth the mixture of 90 percent potash feldspar—10 percent quartz begins to deform and completes deformation before any other mixture and is therefore the deformation eutectic of this feldspar and quartz. The intervals between the deformation of this mixture and the deformation of the mixtures containing 5 percent more or less quartz are so small

Trans. Am. Cer. Soc. Vol. XV Fig. 2 Watts



that in commerce it would hardly be noted unless carefully watched for. The pure feldspar deforms at the same temperature and rate as the 95 percent feldspar-5 percent quartz mixture, and only when a mixture of 80 percent feldspar-20 percent quartz is reached does any noticeable difference appear in the behavior of the cones. This mixture is slightly more refractory than the pure feldspar. The mixture 65 percent feldspar-35 percent quartz is hardly more than $\frac{1}{2}$ a cone harder than the pure feldspar.

Conclusions. Feldspar high in potash and very low in soda content is very slightly affected by additions of quartz or flint. Substitution of quartz for feldspar up to 20 percent may be made without materially affecting the temperature at which deformation begins or is completed. Substitution of quartz for feldspar up to 35 percent may be made without affecting the deformation temperature more than $\frac{1}{2}$ cone. The foregoing indicates the futility of ascertaining the extent to which feldspar contains quartz as an adulterant by the deformation test alone.

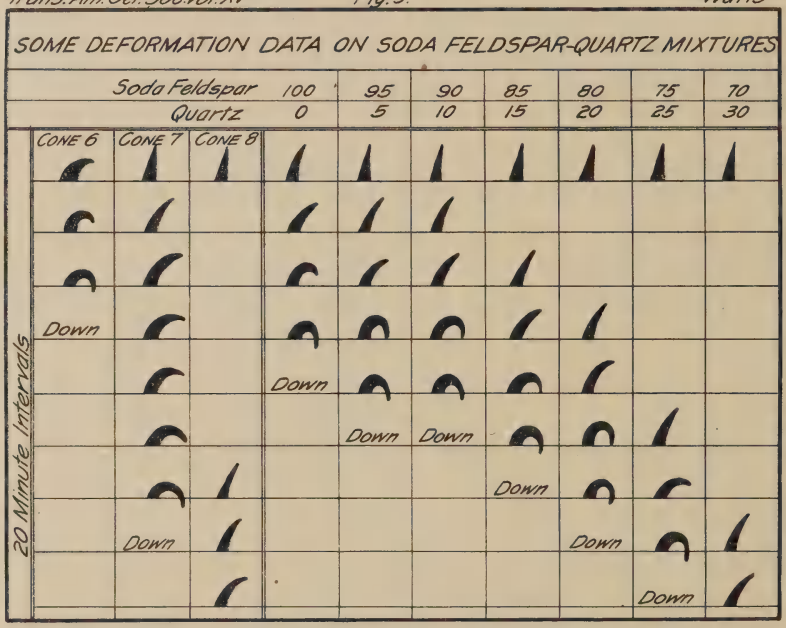
DEFORMATION STUDY OF SODA FELDSPAR-QUARTZ MIXTURES

Soda feldspar used		*Quartz used*	
H_2O	0.20	Loss in ignition	0.11
SiO_2	68.18	SiO_2	99.18
Al_2O_3	20.12	Al_2O_3	0.00
Fe_2O_3	0.05	Fe_2O_3	0.26
Tio_2	trace	TiO_2	0.01
CaO	0.85	CaO	0.01
MgO	0.05	MgO	0.01
K_2O	0.66		99.58
Na_2O	9.38		
	99.49		

These materials were ground to pass 200-mesh sieve and mixed in the proper proportions in the dry state. A small amount of dextrine solution was then added to each mixture and they were molded into cones similar in size and shape to the standard pyrometric cones of commerce against which they were to be tested.

The results of the test follow. The percentages of soda feldspar and quartz in the various mixtures are recorded across the top of Figure 3, and the time and the temperature intervals, as indicated by the deformation of standard cones, are shown along the left margin of the diagram.

The above data indicate that soda feldspar is not affected by additions of quartz in a manner similar to potash feldspar. No addition of quartz up to 70 soda feldspar-30 quartz mixture begins to deform or completes deformation at a lower temperature than pure soda-feldspar. The mixture of 75 soda feldspar-25 quartz however deforms more quickly after its deformation temperature is reached than does the pure soda feldspar. The rate



of deformation as indicated by time intervals is more rapid with soda feldspar, and with all mixtures of soda feldspar and quartz, than with potash feldspar or any mixture of potash feldspar and quartz. Thus rapid deformation rate in soda feldspar-quartz mixtures may be highly desirable in some glazes where fluidity is often desired but in porcelain bodies, this would be a fault since the shorter the deformation range the greater the danger of warping.

COMMERCIAL POTASH FELDSPAR—QUARTZ MIXTURES

Another feldspar-quartz study, which falls between the potash feldspar and the soda feldspar used in these investigations, is of interest here as indicating the possible direction of the curve of deformation eutectics between these two extremes. This feldspar contains 50 percent more soda feldspar than the potash feldspar just studied and is a good average of the feldspar offered for sale as potash feldspar. For convenience it will be referred to as commercial potash feldspar.

Analysis of commercial potash feldspar

H_2O	0.17
SiO_2	65.37
Al_2O_3	17.92
Fe_2O_3	0.02
TiO_2	trace
CaO	0.17
MgO	trace
BaO	0.15
K_2O	13.05
Na_2O	2.10
	98.95

Quartz same as in previously presented studies.

The materials were ground and the mixtures prepared in the same manner as the previous feldspar-quartz studies. The standard cones against which this series was tested included cones 8 and 9. The soda feldspar-quartz study was within the range of standard cones 6, 7 and 8, and the potash feldspar-quartz study was within the range of standard cones 9 and 10. Hence it is shown that this feldspar falls between these two although a careful study reveals the fact that this commercial potash feldspar-quartz study more nearly approaches the regular potash feldspar study than the soda feldspar-quartz study.

This study shows that the increase in soda content causes the deformation eutectic to almost disappear and leaves only the rate of deformation to indicate that such eutectic exists. The rate of deformation of the mixtures is somewhat faster than the pure potash feldspar-quartz mixtures but much slower than the pure soda feldspar-quartz mixtures.

GENERAL CONCLUSIONS ON FELDSPAR-QUARTZ DEFORMATION STUDIES

From these deformation studies it appears that pure potash feldspar may be expected to deform about cone 10, and that 10 percent replacement by quartz will lower the temperature of deformation of the feldspar to a noticeable extent but will not increase the rate of deformation.

If a small proportion of the potash feldspar is replaced by soda feldspar (2 percent Na_2O), the mixtures with quartz do not in any case begin to deform at a lower temperature than the feldspar. However, the mixture of 95 percent feldspar and 5 percent quartz begins to deform at the same time but completes deformation slightly ahead of the pure feldspar. The mixture of 90 percent feldspar and 10 percent quartz begins to deform noticeably after the pure feldspar and the 95 percent-5 percent mixture, but completes deformation at the same time as the 95 feldspar-5 percent quartz mixture. Thus 90 percent potash soda feldspar-10 percent quartz mixture has a greater rate of deformation than the potash-soda feldspar itself. All mixtures of this feldspar with quartz show a tendency to deform more rapidly after deformation begins than does the pure feldspar.

The soda feldspar-quartz mixtures show no evidence of lower deformation temperature than pure soda feldspar, and increases of quartz replacement for feldspar in these mixtures increases with notable regularity the temperature at which deformation begins. The mixture 75 percent soda feldspar-25 percent quartz deforms more rapidly after deformation begins, and all mixtures of soda feldspar and quartz as well as pure soda feldspar deform much more rapidly after deformation begins than do the potash or potash-soda feldspars or any of their mixtures with quartz.

CAUTION REGARDING INTERPRETATION OF THE ABOVE DATA

The above data must not be interpreted as indicating that commercial feldspars containing quartz are of equal value to pure feldspars. Any adulteration by quartz means the necessary use of an additional amount of the feldspar-quartz mixture in order to furnish the necessary feldspar for fluxing purposes. On the other hand, the percent quartz content of the body which is added as

ground flint must be reduced by the amount of quartz added with the feldspar. For example,—a body having the composition 20 percent feldspar, 35 percent flint and 45 percent clays is to be made using a commercial feldspar which contains 80 percent feldspar and 20 percent quartz. In order to introduce the proper amount of feldspar, the 20 percent must be considered as 80 percent of the commercial feldspar, which means that 25 percent of commercial feldspar (20 parts feldspar plus 5 parts flint) must be used. The 5 percent quartz added with the feldspar must be deducted from the 35 percent flint in the recipe leaving 30 percent flint to be added as such. The actual working recipe of the above body would be 25 percent commercial feldspar, 30 percent flint, 45 percent clays. Thus it is shown that the adulteration of feldspar by quartz does not in any way make the feldspar more active in the pottery mixtures unless the mixture contains no flint.

DISCUSSION

Mr. Watts: The point involved is merely to show the results of the mixing of feldspars, i.e., potash and soda feldspar, in order to get the softest mixture of the two; and that, I believe, is sharply brought out in the diagrams.

Mr. Doe: What is the proportion of the softest mixture?

Mr. Watts: Sixty-nine of albite and twenty-nine of orthoclase.

Mr. Doe: You could pretty nearly say then 70 to 50 parts of albite?

Mr. Watts: I should say from 70 to 53 parts albite gives you the minimum fusibility or the lowest fusibility; and as you increase the soda spar content, you slowly increase the deformation temperature, but the rate of deformation remains about the same. As you increase the potash content, you increase the temperature of deformation, but the rate of deformation becomes slower all the time.

Mr. Doe: How are these tiles made, Mr. Watts?

Mr. Watts: I stated that they are pyrometric cones of those materials ground together and mixed with just sufficient dextrine to hold them in cone form. They are simple cones made identical with the pyrometric cones of commerce.

Mr. Doe: How were they burned?

Mr. Watts: They were burned in a muffle furnace, about the same kind of furnace as was described by me in last year's Transactions; it is a muffle furnace about 12 by 10 by 18 inches. The temperature was very evenly distributed throughout; and a period of about thirty hours is occupied in reaching the temperature at which deformation begins, so that we have practically a uniform distribution of heat throughout the muffle. The atmosphere is always oxidizing so we have no difficulty from that.

Mr. Doe: You spoke of the presence of kaolinized material; is that actually kaolinized material or simply alumina and silica?

Mr. Watts: There is evidence of some kaolinization having occurred. We have no known mineral at the present time between feldspar and kaolin; that is, we have no mineral established. The existance of more or less kaolin—I prefer to call it kaolinized material— is apparent in the first place owing to the presence of combined water; and that combined water I find checks, in almost every instance, with the loss of alkali, indicating that whenever the feldspar breaks down, the resultant product takes up water in combination. Now, that question is a thesis in itself, and I have not attempted to do anything with it; but the data, so far as presented, has shown that the water of combination certainly does appear, almost exactly in proportion, with the amount of alkali lost.

Mr. Doe: Does that apply to selected samples of feldspar which you would obtain in a quarry where they presented no external appearance of kaolinization when examined?

Mr. Watts: Yes, I have never taken any feldspar from the surface at all. These represent absolutely fresh feldspar, feldspar which has in most instances lost very little, if any, of the clearness of its crystal face. To anyone but a petrographer there wouldn't by any evidence of kaolinization at all, and generally the combined water amounts only to 1/2 or 3/4 of 1 percent. If you make the test carefully, you will find in every feldspar a certain amount of combined water.

Prof. Orton: Isn't it true that in almost every sample of feldspar you look at under the microscope, you can see a cloudy rim around the edge of the crystal, showing that the action has begun?

Mr. Watts: That is true in a great many cases. Where the material is ground, the grinding has caused some confusion because of the fact that very finely ground material has sometimes

been interpreted as kaolinized material, when it really is possibly some other very finely divided material. Moreover, the edges of feldspar particles are very often found to be scummed over with kaolinized material, and for that reason, where we make microscopic investigation by means of powder, we invariably wash the powder with a dilute ammonia solution in order to take in suspension this kaolinized material and thus be able to see the feldspar in its clearest and best light. So, I think it will be generally agreed that there is almost invariably a small amount of more or less kaolinized materials.

Prof. Orton: The point I had in mind was this; I have seen slides made from perfectly transparent and beautifully crystallized species of feldspar, which to all intents and purpose, as far as one could see, were absolutely unaffected by weathering, and yet when viewed in the petrographic microscope, it would be found there was a slight difference in tint between the center of the crystal and the exterior. You could trace this difference along the margins and also along the cleavages running back into the crystal. Now, to the unaided eye, it all seems like glass, and there was no evidence whatever of breakdown of crystal to the eye; but under the petrographic microscope, it was possible to distinguish it. These slides had been cut out of the middle of big blocks. The petrographer in charge told me at the time that they never expected to be able to cut a feldspar crystal without finding some slight evidence of alteration, though usually alteration had not progressed to the point where there would be dusting off of kaolinite or anything approaching it.

Prof. Parmelee: Were these prepared by grinding with water?

Prof. Orton: Yes, I suppose they had been ground with water, but probably finely polished with rouge.

Prof. Parmelee: Don't you think that would introduce a disturbing factor?

Prof. Orton: I hardly think it would explain what was seen. The grayness along the cleavages went back into the depths of the crystal in such a way that it would not suggest water ever having reached them by surface grinding.

Mr. Doe: Do you find naturally mixed feldspars deforming as artificial mixtures do—relatively, that is?

Mr. Watts: I will be able to show, in another paper before the

Society, exactly comparable results in artificial and natural mixtures of feldspar and quartz. As to whether feldspars deform in that way, I cannot say exactly, except that, as I said at the beginning of this paper, natural mixtures, to the number of about thirty, which I have tested all indicate the existence of this same deformation eutectic. That was really the clue which caused me to make this investigation, the natural mixtures of soda and potash feldspars which we find practically follow the same law, and in my bulletin for the Bureau of Mines, I propose to correlate those and show to what extent they follow this law, but it was impossible to do that in this article, owing to the fact that my data is not sufficiently complete to make those things thoroughly clear.

Mr. Doe: What is the reason they don't close up to 100 percent?

Mr. Watts: These are mixtures based on the two analyses, that is the blending of the two analyses. I have not attempted to show the other materials in the analyses. I have not referred to the kaolinized material or the free quartz of a very small percent of combined water or other minerals. I have included here the essential minerals, for convenience sake. The details of chemical composition are given in the body of the paper.

Mr. Mayer: I think that Mr. Watts has given us a valuable paper. When you were making these experiments, did you notice the effect of color? There is a difficulty in albite; it is a very difficult thing to get a sample of albite that you can use successfully, on account of the color. Did you notice how the color in those soft mixtures compared with that of potash feldspar?

Mr. Watts: Yes, the potash feldspar is invariably clearer, less opaque, than the soda feldspar; but the soda feldspars, if properly selected, are more of a pure white than the potash feldspars. Soda feldspars, in many cases, have been obtained in commerce which are off color slightly, owing to the fact that the price you pay for soda feldspar is considerably less than the price you pay for potash feldspar. The result is that care is not exercised in the selection of the material. There is no reason why soda feldspar should not be as pure white as potash feldspar; and my experience is that it has been, in nature, but you never find a soda feldspar that will fuse down to as clear a glaze as potash feldspar.

Mr. Mayer: Where the question of price is eliminated and you are trying to get the best you can for color, I have never been

able to get one yet that will compare with potash feldspar. There are specks and a brown, more or less dirty, color in connection with soda feldspars and that is why I ask the question I did about your samples.

Mr. Watts: These samples are, as a rule, superior to the potash feldspars. I believe they are a truer white; the potash feldspars tend to cream or pink, whereas the soda feldspars are a pure mat white.

Mr. Mayer: They would be very interesting feldspars for us to get hold of, commercially.

Mr. Watts: Remember this, that where you want a minimum fusing point, regardless of the rate of warping, where you can take care of your warping by means of other materials in your body and you simply want to use the minimum amount of feldspar, in order to get the vitrifying action, you get it apparently in the ratio of 69 percent albite and 29 percent of orthoclase, or in that neighborhood. Now, if you cannot stand for quite so much warping, that is if you are in danger of warping, then you must go towards the orthoclase end. However, if you want to lower your vitrifying temperature, you can easily do it between cone 9 and cone 10, which you know is about the deformation temperature of very hard spars; you can bring it back to, say, cone 7. You get just as long a range of deformation at cone 7, with 29 percent of albite and 69 percent of orthoclase. If you study the diagram carefully, you will find that a certain amount of albite can be introduced without materially injuring your rate of deformation, and the rate of deformation always indicates the tendency to warp on the part of your ware.

I have not worked out, as yet, the influence of quartz additions to this eutectic mixture. That will be included also in my bulletin for the Bureau of Mines. You see every time we find a new minimum deforming mixture, we immediately have to go through all our work of testing with quartz and kaolins, in order to get the action on that particular combination. The result is that the process of investigation is quite slow; but the indications are that quartz mixtures with this feldspar will act very much like the mixtures with feldspar I showed you last year and which you will find described in Volume 14.

Mr. Mayer: There's one thing I would like to point out; the use of albite is a very tempting thing for the potter, at times, on account of what is said to be the low fusing point of it but there is difficulty about getting albite of a good color. I know one factory, in Baltimore, that got into a rather serious mess in regard to the use of albite. They made a tremendous lot of ware out of Maryland albite, and what they didn't break, they couldn't give away. A factory in Beaver Falls also got into trouble using albite. A piece of ware made from albite has practically no ring to it. I made the statement about the ring of ware made from albite at one of our meetings, and it was questioned very seriously; but I unfortunately had made a lot of ware and it cost me a good deal to find out what the result was. I think that's a thing worthy of consideration.

Mr. Watts: I recollect that incident and remember that I gave a paper several years ago in which I compared the ring of the soda feldspar and the potash feldspar and I found, as Mr. Mayer stated, that there is a very decided difference and the albite porcelain has a woody, dead sound; but I had not in mind, nor would I suggest, that anyone undertake to use the albite in its pure state. Really there is no advantage in using more than fifty percent of soda feldspar. In reality, you find very rarely a potash feldspar that runs very much over 12 to 13 percent of potash and it will generally run about two percent of soda. That two percent of soda will represent the equivalent of three percent of potash or about 20 percent of soda feldspar. The ordinary feldspar you use in commerce is just about that. You call it potash feldspar; in reality it generally contains 20 percent of soda feldspar.

Mr. Mayer: Very often more than that.

Mr. Doe: What effect would lime have on such mixtures?

Mr. Watts: Lime, I have not tested to any great extent. There is always a certain amount of lime in soda feldspar; the percentage of lime however is generally, almost invariably I might say, so small in proportion to the content of soda, that in soda-potash feldspar the lime is really not serious. If your lime content increased till it was four or five percent, I should say that it would act as seriously as an excess of soda would, although I have no positive data covering that point.

THE MELTING POINTS OF REFRACTORY MATERIALS

BY C. W. KANOLT

Before discussing the determination of melting points it is well to consider what a melting point is. We are accustomed to thinking of a melting point as a temperature at which a substance changes from a condition in which it does not flow perceptibly under its own weight to a condition in which it flows readily. Although this is often the temperature of most importance practically, no rational definition of the melting point can be based upon this conception. For example, when glass is heated, the transition from its ordinary condition to a distinctly fluid condition is a very gradual one and occupies a range of several hundred degrees.

A melting point can be precisely and rationally defined only as a temperature at which a crystalline or anisotropic phase and an amorphous or isotropic phase of the same composition can exist in contact in equilibrium. This true melting point may be either above or below the apparent melting point or softening point. Some substances which possess perfectly definite true melting points, undergo changes resembling fusion at lower temperatures. Solids in general become softer when heated; they may become so soft as to yield to their own surface tension, with the result that sharp corners are rounded off. Rutile, in its natural, slightly impure condition, melts at about 1700°C. The melting point is very definite, there being a sharp transition from a rather soft solid to a liquid of low viscosity with a considerable absorption of heat. Yet at temperatures 100 degrees or more below the melting point, corners are rounded off and small particles become sintered together. The sintering of pure clay is probably a similar phenomenon of surface tension.

The opposite phenomenon of a softening temperature above the true melting point is exhibited by silica. The true melting point of silica is about 1600.[1]

However, the fused silica possesses such extreme viscosity near

[1] Day and Shepherd, Jour. Am. Chem. Soc. 28, p. 1089, (1906).

the melting point that it does not flow or change shape distinctly until considerably higher temperatures are reached. I have obtained 1750° as the apparent melting point of pure silica, i.e., the temperature at which it flows distinctly. This temperature however, is naturally a very indefinite one.

While the above definition of the true melting point is satisfactory for the case of a pure substance, so complex a mixture as an ordinary fire brick usually has no single definite melting point according to this definition, since several anisotropic phases may be present, all differing in composition from the isotropic phase produced by fusion. We can then only select the temperature at which the transition from a rigid to a fluid state seems most distinct, and can call this the melting point only by apology. In the case of fire bricks, the transition temperatures so found are fortunately sufficiently definite to make their determination of practical value. I have taken as the melting point the lowest temperature at which a small piece of the brick could be distinctly seen to flow.

The melting point of a brick is, of course, not the only property to be considered in determining its fitness for a given purpose. Its crushing strength cold, its behavior under load conditions when heated, and its resistance to fluxes may all be important. Bleininger and Brown[2] have made a large number of tests of fire bricks under load conditions at 1300°C., this work being carried out at the Pittsburgh Testing Station of the Bureau of Standards, which station was at that time the Technologic Branch of the United States Geological Survey. The chemical composition, crushing strength cold, porosity and density of these samples are given by Bleininger and Brown. They also determined the Seger cone numbers corresponding to the softening temperatures of the bricks.[3]

I have determined the melting points of a large number of samples of fire bricks including many of these tested under load

[2] Bureau of Standards, Technologic Paper No. 7 (1912).

[3] See also: Hofman and Demond, Trans. Am. Inst. Mining Eng., 25, p. 42 (1894); Hofman, Trans. Am. Inst. Mining Eng., 25, p. 3 (1895), 28, p. 43 (1898); Hofman and Stroughton, Trans. Am. Inst. Mining Eng., 28, p. 440 (1898); Gary, Mitt. k. tech. Versuchsanstalten 14, p. 63 (1896); Jochum, Thonindustrie Zeit., 27, p. 764 (1903); Weber, Trans. Am. Inst. Mining Eng. 35, p. 637 (1904).

conditions by Bleininger and Brown. The experiments were conducted in an Arsem graphite-resistance vacuum furnace[4] (Fig. 1). As a matter of precaution, the specimens were protected by a refractory tube (A, Fig. 1) being placed on a bed of white alundum (fused alumina) in the bottom of the tube. The refractory tubes were usually made of a mixture of 72 per cent kaolin and 28 per cent alumina, these being the proportions for the formation of sillimanite, Al_2O_3, SiO_3. According to Shepherd and Rankin[5] pure sillimanite melts at 1811°. Either sillimanite or kaolin tubes were used with all fire bricks melting below 1800°. The chromite and magnesia bricks were melted in graphite crucibles without protecting tubes. While the sample was being heated, it was observed through the glass window, E, at the top of the furnace.

The temperatures were determined by means of a Morse optical pyrometer of the Holborn-Kurlbaum type[6] which was sighted vertically downward through the furnace window. The use of the optical pyrometer depends upon the assumption that the object sighted upon emits black-body radiation. This is the case if the object is within a vessel at uniform temperature, and is viewed through a relatively small opening in the vessel. This can readily be accomplished in the apparatus used, but under such conditions it would be impossible to distinguish the sample, owing to the uniform brightness of the sample and its environs. In practice, the sample was placed slightly below the hottest part of the furnace in such a position as to be barely distinguishable. This requires only a temperature difference of about five degrees.

The results of tests made in this way are condensed in Table I.[7]

The melting points of the pure refractory oxides are also of importance, but few of them have been known, for there are several difficulties to be overcome in their determination. It is necessary to use very high temperatures, to find crucible materials in which the oxides can be heated without contamination, and to

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[4] Arsem, Jour. Am. Chem. Soc., 28, p. 921 (1906); Trans. Am. Electroch. Soc., 9, p. 153 (1906).

[5] Shepherd and Rankin, Am. Jour. Sci., 28, p. 301 (1909).

[6] Holborn and Kurlbaum, Sitzbar. d.k. Akad. d. Wissensch. zu Berlin, June 13, p. 712 (1901); Ann. der Phys., 10, p. 225 (1902); Waidner and Burgess, Bull. Bureau of Standards, 1, No. 2, (1904); Mendenhall, Phys. Rev. 33, p. 74 (1911); Henning, Zeit. f. Instrumentenkunde 30, p. 61 (1910).

[7] The complete results and further details of this part of the work may be found in Bureau of Standards Technologic Paper No. 10 (1912).

Trans. Am. Cer. Soc. Vol. XV Fig. 1. Kanolt

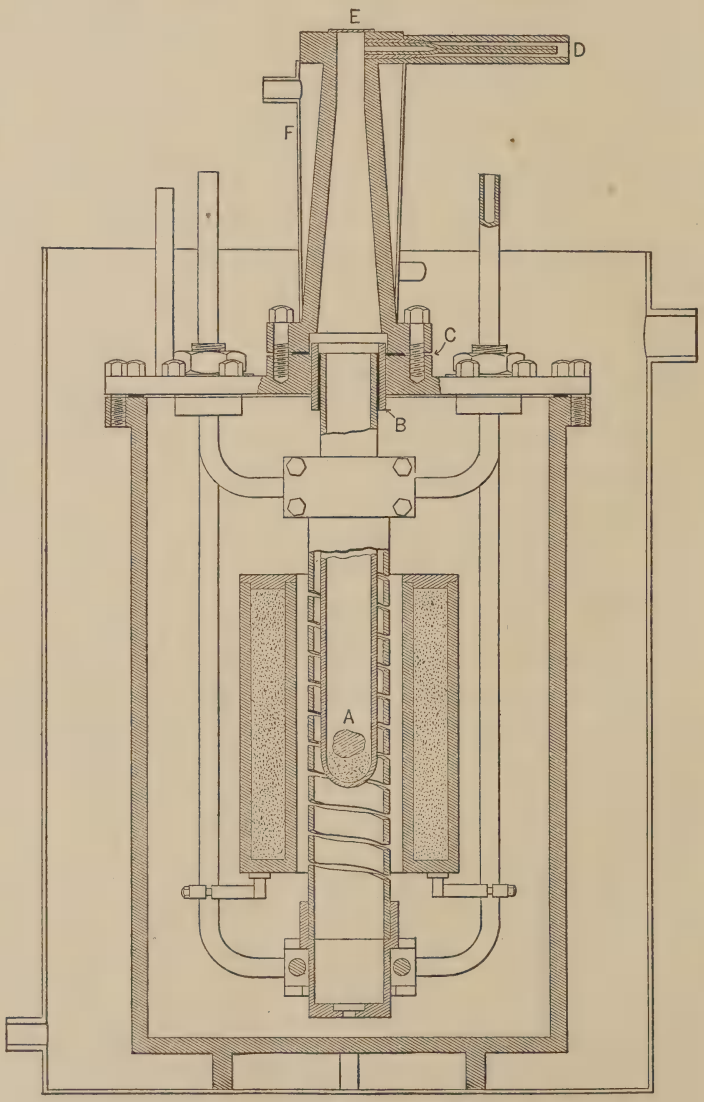


Fig. 1

TABLE I

MATERIAL	NUMBER OF SAMPLES	TEMPERATURE OF VISIBLE FLOW
		degrees
Fireclay brick	41	1555–1725 (mean 1649)
Bauxite brick	8	1565–1785
Silica brick	3	1700–1705
Chromite brick	1	2050
Magnesia brick	1	2165
Kaolin	1	1735–1740
Bauxite	1	1820
Bauxite clay	1	1795
Chromite	1	2180

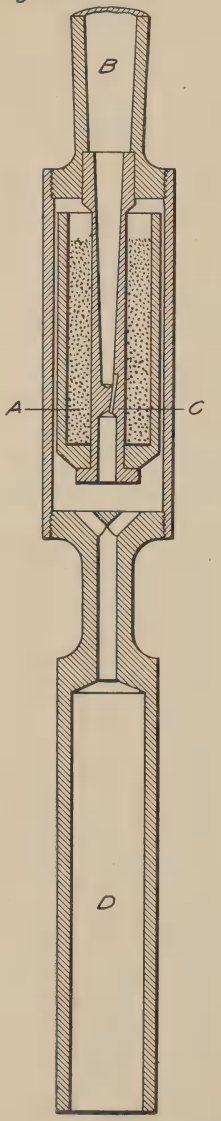
make accurate determinations of the temperature. Only an optical or a radiation pyrometer can be used at these temperatures, and their use may be interfered with by the evolution of a dense smoke from the vaporizing oxide. If the oxide can be heated in a vacuum the smoke can be avoided, but some oxides, including lime and magnesia, are completely vaporized in a vacuum before their melting points are reached.

I have used the Arsem furnace for work upon oxides, filling the furnace with a non-oxidizing gas, at atmospheric pressure, when the vaporization of the oxide prevented the use of a vacuum. The furnace requires more power at atmospheric pressure, and it has been found advisable to change somewhat the design of the heater.

Magnesia can be melted without contamination in graphite. Some other oxides, such as lime, readily form carbides when heated in graphite, and still others, such as chromium oxide, are reduced too rapidly to metal. Tungsten has been found to be a suitable crucible material for such of these oxides as have been tried.

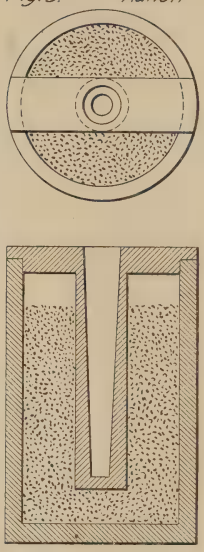
The difficulty caused by the smoke was obviated by inserting into the top of the furnace a tube, the lower end of which is small and thin-walled, and is inserted in the oxide. The optical pyrometer is sighted down this tube. To prevent any smoke from entering this tube through cracks or pores, gas is driven into the tube at a small pressure and passes out through the cracks and pores or through a small opening at the bottom. The apparatus as used with magnesia is shown in Fig. 2. The magnesia is shown

Trans. Am. Cer. Soc. Vol. XV
Fig. 2 Kanolt



at A. The pyrometer is sighted through B, which also carries the gas current. The gases pass through a very small opening at C, so made that light cannot pass directly through it. The gas and smoke are carried away by the tube D. If they were allowed to escape directly in contact with the hot part of the heater they would be likely to burn a thin place in it.

Trans. Am. Cer. Soc. Vol. XV
Fig. 3. Kanolt



When it was possible to use a vacuum, a crucible of the form shown in Fig. 3 was used, the pyrometer being sighted down the central tube, which was made of the same material as the crucible, either graphite or tungsten. If the top of the crucible is left partially open, the behavior of the oxide can be observed at the same time that the heating curve is plotted.

At present, the work upon three oxides, MgO, Al_2O_3, Cr_2O_3, has been completed. The results are given in Table II.

In no case were the determinations of the melting point of a material all made with the same pyrometric apparatus. The melting point of platinum was determined as a check upon the temperature measurements. For this purpose an iridium tube furnace was used, the platinum being melted in a tube of magnesium aluminate.[8] Both heat-

[8] Heinecke, Zeit. angew, Ch., 21, p. 687; (1908).

TABLE II

MATERIAL	INDIVIDUAL DETERMINATION	WEIGHT	WEIGHTED MEAN	PREVIOUS DETERMINATIONS
	degrees		*degrees*	*degrees*
Cr_2O_3.....	1990	3		2059 Ruff and Goecke.[9]
	1991	1		
	1982	1	1990	
	1979	2		
	2000	3		
Al_2O_3.....	2045	3		1880 Hempel[10]
	2053	1		2020 Ruff and Goecke
	2053	2	2049	
	2041	2		
	2055	3		
	2046	2		
MgO.....	2808	3		2250 Hempel[10]
	2780	2		1910 Goodwin and Mailey[11]
	2818	3	2800	
	2771	1		2000 Lampen[12]
	2799	2		2050–2100 Saunders[13]
	2799	3		
Pt.....	1745	1		1980–2023 Mendenhall and Ingersoll[14]
	1751	3		
	1753	3	1755	
	1761	3		
	1759	3		

ing and cooling curves were obtained. The value accepted by the Bureau of Standards as the melting point of platinum is 1755°.

Work on other refractory oxides is in progress. The melting point of lime, like that of magnesia, has been found to be much higher than previous determinations.

Bureau of Standards,
Washington, D. C.

[9] Zeit. f. angew. Ch. 31, p. 1459 (1911).
[10] Ber. Inter. Kongress Angew. Chem., 1, p. 715 (1903).
[11] Phys. Rev. 23, p. 22 (1906).
[12] Jour. Am. Chem. Soc. 28, p. 846 (1906).
[13] Trans. Am. Electrochem. Soc., 19, p. 333 (1911).
[14] Phys. Rev. 25, p. 1 (1907).

DISCUSSION

Prof. Parmalee: I would like to ask Dr. Kanolt how large a sample can be melted in that furnace?

Dr. Kanolt: The inside diameter of the heater is about $1\frac{5}{8}$ inches. The fire brick samples used were only $\frac{1}{2}$ to $\frac{3}{4}$ inch in diameter. Dr. Day, the other day, emphasized the value of work on small samples. We do not rely on a single small sample, but we take a number of samples of material, different samples from the same brick, and are able to repeat the melting point very closely, except in cases where there are obvious lumps of foreign matter in it.

Prof. Parmalee: The reason I asked that question was because I had that condition in mind. I should think small fire brick samples of that sort would give rather discordant results, at least if you take several samples.

Dr. Kanolt: The results were more concordant than I expected. There was very little difference except in a few cases in which there were lumps in the material, and then the spots in the brick could be seen to melt at a different temperature from the mass.

Mr. Barringer: I am particularly interested in the use of this vacuum furnace. Is it not made by the General Electric Company?

Dr. Kanolt: Yes sir.

Mr. Barringer: A furnace of that type was designed seven or eight years ago by W. C. Arsem, of the General Electric Company, and has proven of value in all sorts of research, particularly in the examination of refractories and rare metals. I think it is a most excellent furnace for that sort of work. I am glad to see it being used, because I know it required five or six years to work out fully, and that the Research Laboratory of the General Electric Company has depended upon it for much high temperature work in their research work. Mr. Arsem has checked the Seger and Orton cones in this furnace. He burned one cone after another and, although the cones are occasionally claimed to be poor temperature indicators, we were able to check with the furnace temperatures as shown by the energy curves, showing that for all practical purposes these cones indicate sufficiently close to the actual temperature. Mr. Arsem had a curve of the energy put into the furnace at different temperatures and claimed he could

get within a few degrees simply by noting the energy being consumed.

In a lot of our work with this furnace, we used an alumina crucible, and you might be interested to know how we make these alumina crucibles. We take the aluminum hydrate and fire that first in a porcelain kiln, and this dehydrated alumina is mixed with a gum binder. The crucibles are pressed in steel moulds and then fired in the porcelain furnace and finally fired in the vacuum furnace, if greater strength is desired. As Dr. Kanolt has pointed out, the life of such a crucible is short and it is necessary to always have a number of crucibles on hand.

Mr. Frink: I would like to ask what the current consumption is?

Dr. Kanolt: According to Arsem's results, the furnace takes up to about 13 or 14 kilowatts at 3,000°C. and that means at lower temperatures, say the melting temperatures of fire brick, something like 5 kilowatts. In the work with magnesia, we used much more than that, partly because we were not working with the vacuum, but also because it was necessary to do the heating more rapidly, and we used, perhaps, 25 kilowatts. I should add that the furnace can be seen at the Bureau tomorrow; and it is a furnace that we use practically every day in the year, not only for melting points of this kind, but for metals and slags.

Dr. Sosman: Were both heating and cooling curves taken with the oxides?

Dr. Kanolt: With the oxides, the curves were almost all heating curves. There were two reasons for not getting cooling curves; some substances undercool too much, and in many cases, there was not enough oxide left to make a good cooling curve. The material evaporates so rapidly that when the heating curve is completed, there is not very much left. We are able to check our results on the melting point by taking the sample out of the furnace and examining it. We can heat it up to a little below the melting point and again a little above and take it out, and we find that the results so obtained correspond to the melting point as obtained from the heating curves.

Mr. Fiske: I should like to ask in regard to the firebrick. I notice that 41 different samples were tested and the melting points,

I think, varied 170 degrees. Were they different grades of brick from different parts of the country?

Dr. Kanolt: They were from 9 different states, and 17 manufacturers.

Mr. Fiske: The reason I asked the question was that some two or three years ago in connection with the brick department of our business, I thought it would be desirable to get the melting points of all the different fire bricks sold in our market. I anticipated there would be a very great difference in melting points, because the practical performance of the brick of course shows an immense variation. So I secured the services of Professor Norton at the Massachusetts Institute of Technology, who had an electric furnace something like the one described, and we collected together some eight or ten different samples, varying from the very highest grade of flint clay brick we could obtain from western Pennsylvania to the very cheapest and commonest kind of second grade New Jersey brick (Laughter). I see that description raises a laugh. That is not intended to reflect any discredit on the New Jersey brick, because I believe New Jersey manufactures as good brick as are made in Pennsylvania, but I happened to take—purposely took—one of the lowest grade bricks in order to determine what is supposed to be a very great difference of melting point. I was very much astonished to find that the difference in melting point was just 55 degrees C. between the highest grade flint and clay and the poorest grade New Jersey brick, showing that the melting down of the cheap brick in ordinary practice is not due to heat entirely, but must be due to the fluxing action of gases.

Dr. Kanolt: I have mentioned that this melting point is not the only thing, and the test under load conditions is also very important. Many of these same bricks were tested under load conditions by Bleininger and Brown, and in many cases there is not very much relation between the actual melting point and the failure under the load. The relative importance of the tests in any particular case depends somewhat upon the conditions under which the brick is to be used.

A NOTE ON RATIONAL ANALYSIS AND GLAZE FIT

BY CHARLES F. BINNS

This note is offered in accordance with a suggestion made by the writer at the last meeting of the Society and published on page 377 of Vol. XIV of the Transactions as follows: "If he (Mr. Purdy) had made up bodies of the same rational composition, using different clays, I wonder if he would have found the same discrepancies."

In accordance with this idea the four bodies reported upon by Mr. Purdy have been made up, using six of the same clays as those used in his investigation. These clays are:

51	Mandle Sant ball clay No. 2
53	A Kentucky clay
55	English ball clay No. 12
82	Tennessee ball clay No. 1
98	Johnson Porter ball clay No. 9
104	English ball clay M and M,

and in addition to these:

253	Florida clay
255	English ball clay, Golding

Samples of the six clays were procured from the Department of Ceramics, O. S. U., by the courtesy of Profs. Orton and Purdy and were taken from the same stock as was used by the latter.

The following are the calculated rational composition of these clays, Mr. Purdy's figures being taken for the first six.

	51	53	55	82	98	104
Clay substance..	97.6	60.4	74.8	90.6	83.11	77.4
Feldspar.....	2.4	11.7	16.11	7.3	4.91	8.4
Quartz.....		27.9	9.04	2.1	11.98	14.2

	253	255	DILLSBORO KAOLIN	MAINE SPAR
Clay substance.....	98.5	73.8	95.4	7.3
Feldspar.....	1.5	15.9	3.6	85.1
Quartz.....		10.3	1.0	7.6

The kaolin is the same as that used by Mr. Purdy; but there being no Canadian feldspar at hand, Goldings Maine spar was substituted. The four bodies are those situated at the angles of the parallelogram which Mr. Purdy considers to limit the area of practical bodies. They are:

	A	B	C	D
Clay substance	40	52	52	40
Feldspar	20	20	8	8
Quartz	40	28	40	52

The same specification was followed except that instead of taking 20 parts of ball clay in each case, 20 parts of the required clay substance was derived from the ball clay.

CLAY 51

	A	B	C	D
Ball clay	20.49	20.49	20.49	20.49
Kaolin	19.24	31.89	32.99	20.27
Feldspar	21.97	21.60	7.42	7.94
Flint	38.20	26.04	39.10	51.19

CLAY 53

	A	B	C	D
Ball clay	33.10	33.10	33.10	33.10
Kaolin	19.58	34.21	33.04	20.63
Feldspar	18.00	15.19	3.42	3.98
Flint	29.18	18.28	30.18	42.26

CLAY 55

	A	B	C	D
Ball clay	26.71	26.71	26.71	26.71
Kaolin	19.82	32.22	33.31	20.69
Feldspar	17.51	17.06	2.88	3.45
Flint	35.97	23.99	37.04	49.12

CLAY 82

	A	B	C	D
Ball clay	22.10	22.10	22.10	22.10
Kaolin	19.27	31.67	33.05	20.28
Feldspar	20.66	20.25	6.42	6.71
Flint	37.64	25.65	38.69	50.88

CLAY 98

	A	B	C	D
Ball clay	24.06	24.06	24.06	24.06
Kaolin	18.70	31.94	33.05	20.39
Feldspar	21.29	21.05	6.46	7.13
Flint	35.25	23.23	36.30	48.25

CLAY 104

	A	B	C	D
Ball clay	26.0	26.0	26.0	26.0
Kaolin	19.4	31.94	33.03	20.27
Feldspar	20.09	19.56	5.51	6.43
Flint	34.5	22.40	35.41	47.30

CLAY 253

	A	B	C	D
Ball clay	20.30	20.30	20.30	20.30
Kaolin	19.24	31.94	32.60	20.34
Feldspar	22.31	21.75	7.69	8.17
Flint	38.12	26.06	39.40	51.18

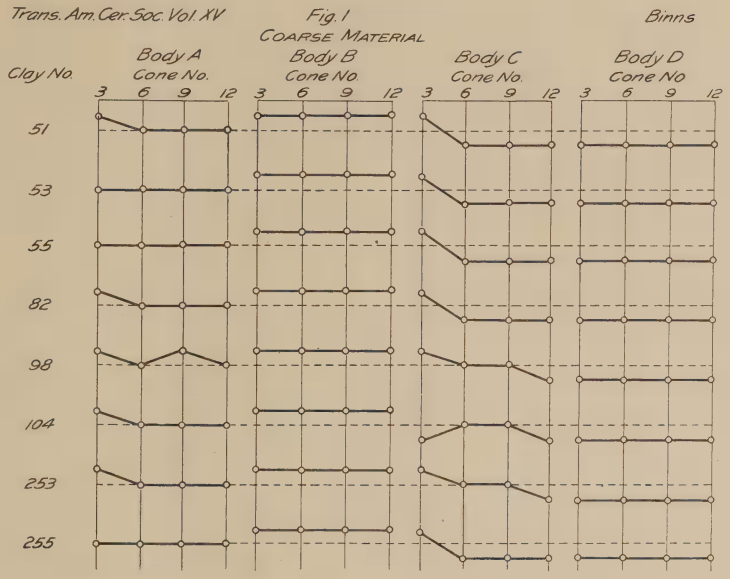
CLAY 255

	A	B	C	D
Ball clay	27.10	27.10	27.10	27.10
Kaolin	19.67	32.49	33.32	20.69
Feldspar	17.50	16.80	2.90	3.47
Flint	35.78	23.61	36.68	48.73

The eight bodies were made up in duplicate, one set of mixtures being blunged and lawned through 100-mesh and the other being ground wet on a ball mill and lawned through 120-mesh. Square tile were then pressed in plaster molds and burned at cones 3, 6, 9 and 12, respectively, two tile being the unit. After burning, the tile were glazed with the same glaze as that used by Mr. Purdy and burned at cone 4. The accompanying diagram has been prepared upon lines similar to those suggested by Prof. Purdy last year, except that the amount of crazing and shivering is not expressed. The points below the mean represent shivering; those above, crazing. The results are that of the blunged mixtures A, five clays crazed at cone 3. The remainder were sound except for one specimen of clay 98 which crazed at cone 9. Of body B, every tile crazed at every heat treatment, of body D, every tile shivered, body C was more erratic, but in five of the eight cases the tile at cone 3 crazed and the remainder shivered. In the other three cases there were sound tile at cones 6 and 9. In this connection it may be mentioned that in the case of a very soft body, such as C at cone 3, it is very difficult to distinguish between crazing and shivering.

In the mixtures which were ground there was even more uniformity though body C is still rather erratic. In body A only two cases of crazing appear, both at cone 3. This seems to be the logical effect of grinding, because added flint is not as fine as the quartz flour which occurs in the clays. The same fact appears in body B, for whereas in the coarse mixtures every piece crazed, in the fine mixtures there are fourteen sound specimens.

It would appear, then, so far as the value of these experiments goes, that there is reason to believe that bodies constructed alike on the principle of rational composition will behave in a similar way in the matter of a glaze fit whatever clay is used in the mix. As a single illustration, clay 104, English ball clay, may be compared with 253, Florida clay. No two clays could differ much more widely in their general characteristics, and yet the made up tiles behave almost exactly alike.


Trans. Am. Cer. Soc. Vol. XV
Fig. 1
Coarse Material
Binns
Clay No.
Body A
Cone No.
Body B
Cone No.
Body C
Cone No.
Body D
Cone No
3 6 9 12
51
53
55
82
98
104
253
255

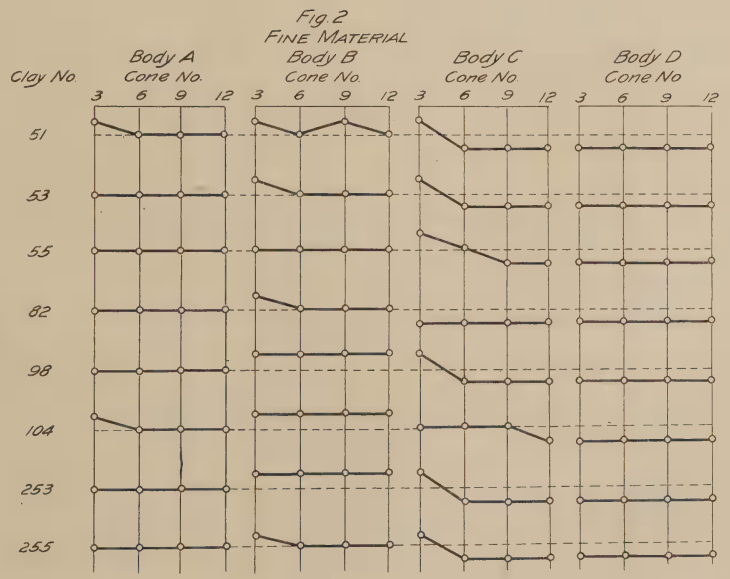


Fig. 2
Fine Material
Clay No.
Body A
Cone No.
Body B
Cone No.
Body C
Cone No.
Body D
Cone No
3 6 9 12
51
53
55
82
98
104
253
255

DISCUSSION

Mr. Purdy: You will remember that two years ago (Vol. XII, p. 92) I drew a diagram showing the practical limits of body composition. I stated at that time that body A would generally fit with any material, i.e., with most any clay, feldspar and flint, provided you had proper physical conditions in the body to make ware at all. Body B would practically always craze, in time. The practical body indicated by the star, when receipts are figured down, would craze or not craze, depending upon your choice of clays. C would craze occasionally; generally it would show a good fit. If D did anything, it would shiver. Last year we had some rational analyses made of the clays, and found that all those bodies were moved over to the left. Notwithstanding that general shift, there was no relation between the rational composition and the shivering and crazing.

The objection to my paper was that it was not rational, that I should have compounded the bodies so that they would always be the same, from a rational composition. This Professor Binns has done, and notwithstanding his conclusion that all bodies of the same rational composition would have the same effect, his own description of the tiles shows that they were not the same. He said that five out of eight crazed; the other three did not craze; or three out of the series of eight shivered and five did not shiver, showing that he himself experienced a variation in the shivering and crazing of bodies made upon the same rational composition. I don't see how he drew the conclusion he did after having thus described the tiles.

I asked Mr. Heubach if Professor Binns had sent tiles. He said, "No, Purdy didn't have tiles, therefore they'd have to believe him as well as Purdy." Purdy has got tiles this time and made on the same plan as Binns and by one of Mr. Binns' students. I handed the analyses to the young man with instruction to select four clays, make up some bodies and burn and glaze them. Here is the student's own note book and here are the tiles he made, and here is the evidence to prove that bodies made on the same rational composition but from different clays do not behave alike in matter of glaze fit.

You remember Mr. Binns said earlier that if they crazed, they would all craze exactly alike. This is not true with these trials; the bodies did not all craze alike, notwithstanding the fact that they have the same rational composition. The physical properties of the clay have a larger control in glaze fit than the rational composition of the clays. I still maintain my contention, not only from my own data, but from data presented by Professor Binns at this time.

Mr. Mayer: I don't know anything of this body, but I would say that a glaze dipped so heavy would craze anyhow. I don't think because that glaze has crazed, it is anything against it, but it is so thick that it couldn't help craze.

Mr. Purdy: He dipped all of the plates dry, hoping to get the glaze as thick as possible so that we have the crazing and shivering tendencies pronounced.

Mr. Heubach: I can't say anything from Professor Binns' point of view; all I know is that he made up the bodies, and afterwards we went over the trials together to check up the results. I myself believe in the rational analysis within the limits which Seger put down for it. If we are dealing with clays that contain nothing but clay substance feldspar and quartz, we may use either method successfully, but if they contain other mineral matter or soluble alkalies, I don't think either the laboratory method or calculated method of rational analysis is reliable.

Mr. Purdy: I don't suppose this subject is of any interest to the people at large; I think they have all decided that they can't control glaze fit from a rational analysis; but I would like to say that a careful reading of Seger will disclose the same statement that he was unable to control glaze fit by mixing his bodies on a rational analysis basis.

THE EFFECTS OF SOME ELECTROLYTES ON TYPICAL CLAYS

BY C. H. KERR AND C. E. FULTON, TARENTUM, PA.

INDEX: 1. Preface; 2. Clays and Electrolytes; 3. Tests Made; 4. Results; 5. Summary.

1. Preface. Much work has been done on the effect of electrolytes on clays in the plastic state.[1] No new methods or new problems are here presented, but there is given an independent set of determinations of the effects of several representative electrolytes upon a fire clay and a ball clay.

2. Clays and Electrolytes. The work was carried on in connection with two clays: 1, Tennessee Ball Clay 3 as representative of the very plastic clays; 2, St. Louis fire clay as representing the general class of plastic fire clays. The electrolytes used were, NaCl, Na_2CO_3, NaOH, $CaCl_2$, $BaCl_2H_2O$, and $AlCl_312H_2O$ in amounts equivalent to the following percentages of the dry reagents in terms of the dry clay; 0.015, 0.025, 0.035, 0.050, 0.10, 0.25, 0.50, 0.75, 1.00, and in some cases also 1.50 and 2.00 percents.

3. Tests Made. In each case the electrolyte was dissolved in a little less water than was needed for mixing the clay. The clay in the air-dried condition was weighed out, and the solution of the electrolyte added. Enough water was then added to give a working mass of the best plasticity. All batches containing electrolytes were made up to be as nearly as possible of the same consistency as the batch without electrolyte. The amount of water required to produce this condition was determined, the figures including also the moisture in the clay. Bars 5 in. by $1\frac{1}{4}$ in. by $\frac{3}{4}$ in. were made, and volume shrinkage was measured by the method of displacement in kerosene.

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[1] The following work deals with clays in plastic state: Bleininger and Fulton, *T. Am. Cer. Soc.*, 14: 827–39 (1912). The remaining references are the most recent ones dealing with clay suspensions.

Purdy, *et al Trans. Am. Cer. Soc.*, 13: 641–4 (1911)

Ashley, *Trans, Am. Cer. Soc.*, 12: 768–817 (1910)

Ashley, *Trans. Am. Cer. Soc.*, 11: 530–595 (1909)

Ashley, Bulletin 388 U. S. Geol. Surv. (1909)

4. Results. First the curves showing the relation between amount of water and the volume shrinkage for each clay were obtained, and the data are shown in Tables 1 and 2. (See Figures 1 and 2.)

TABLE 1—TENNESSEE BALL CLAY 3

Relation of Volume Shrinkage to Percent Water Used

Percent H_2O	*Volume Shrinkage*
37.17	20.56
42.34	25.37
47.50	28.88
52.93	33.07
58.07	33.89

TABLE 2—ST. LOUIS FIRE CLAY

Relation of Volume Shrinkage to Percent Water Used

Percent H_2O	*Volume Shrinkage Percent*
21.68	17.25
21.77	16.85
24.26	19.53
27.02	22.69
27.16	25.09
29.68	27.46
31.38	27.54
32.20	29.43
32.23	22.79

With these data as guides to show the volume shrinkage changes caused by variation in the amount of water used, the series employing the electrolytes were started. The results shown below in tabular and graphic form are averages of three determinations in close agreement. Table 3 shows the volume shrinkage of Tennessee Ball Clay 3, and Table 4 shows the amount of water used in making the test bars from which the data in Table 3 were obtained. Any figure therefore in Table 4 shows the amount of water used in making the corresponding tests in Table 3.

In a similar way Tables 5 and 6 show the corresponding data with St. Louis fire clay, the figures in Table 6 showing the amounts of water used in mixing the samples shown in corresponding positions in Table 5.

TABLE 3—TENNESSEE BALL CLAY 3

Volume Shrinkage Percent

	NaCl	Na_2CO_3	NaOH	$CaCl_2$	$BaCl_2 2H_2O$	$Al_2Cl_6 12H_2O$
0.0	25.69	26.71	26.01	25.78	25.39	25.86
0.015	25.67	25.93	25.22	24.87	24.60	25.53
0.025	24.83	26.00	25.30	24.90	24.29	24.63
0.035	25.17	25.73	25.89	25.01	24.11	24.99
0.050	25.56	26.01	25.83	24.41	24.65	24.76
0.10	24.51	25.68	25.91	24.14	24.39	25.38
0.25	24.71	26.57	26.85	23.82	24.54	25.15
0.50	24.93	27.35	25.97	24.02	23.93	24.45
0.75	25.37	26.89	26.12	25.21	25.55	24.74
1.00	24.60	26.77	25.65	24.60	25.12	24.46
1.50	24.36	26.46	25.53			
2.00	24.90	27.07	24.59			

TABLE 4—TENNESSEE BALL CLAY 3

Amounts of Water Used in Tests of Table 3

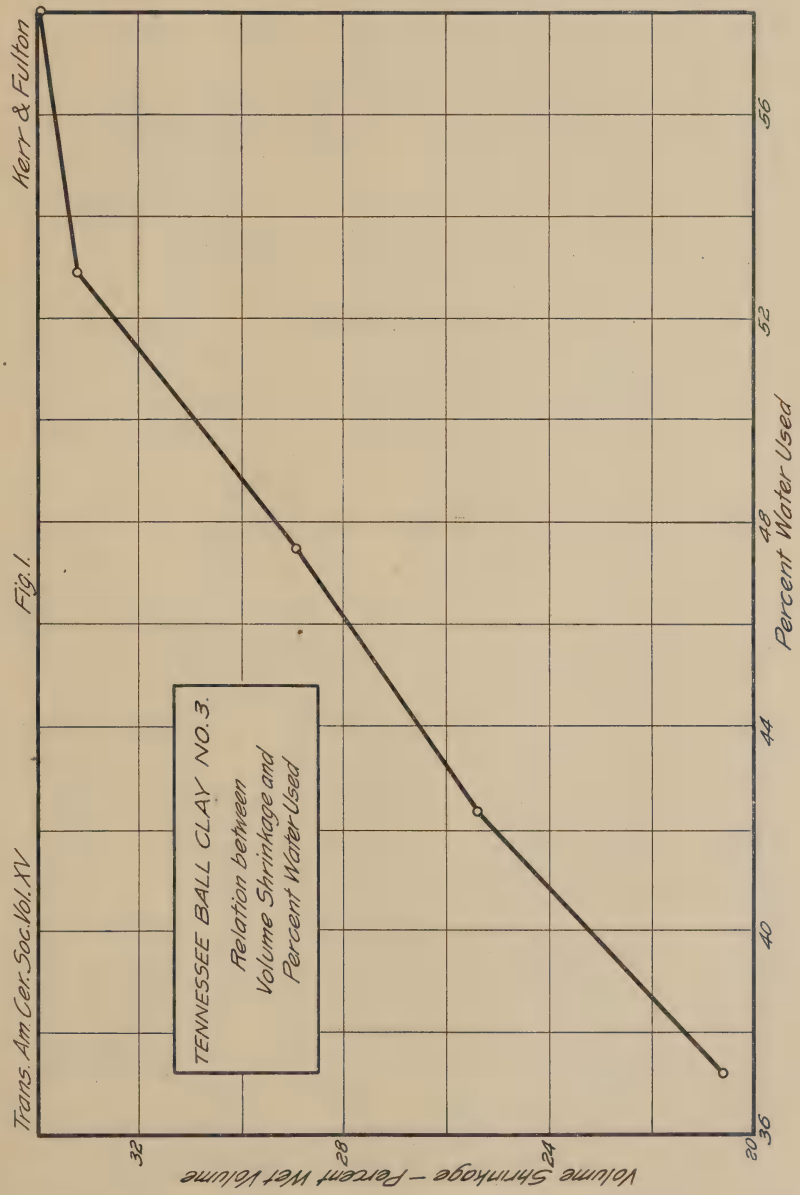
	NaCl	Na_2CO_3	NaOH	$CaCl_2$	$BaCl_2 2H_2O$	$Al_2Cl_6 12H_2O$
0.000	37.1	37.6	37.4	37.4	37.1	37.4
0.015	37.3	37.8	36.5	37.5	37.0	37.3
0.025	36.7	37.9	36.9	37.1	37.1	37.1
0.035	36.8	37.7	37.0	37.5	37.2	37.5
0.050	36.9	37.6	37.1	36.9	37.1	36.9
0.10	36.9	37.1	37.6	37.1	37.4	37.1
0.25	36.3	37.6	37.3	36.8	37.8	36.8
0.50	36.5	37.0	34.7	37.0	37.8	36.5
0.75	37.0	35.7	33.1	37.0	37.5	37.0
1.00	36.4	36.2	33.4	36.4	37.4	36.9
1.50	35.8	36.0	35.0			
2.00	35.7	35.5	34.5			

Figures 3 and 4 show graphically the data of Tables 3 and 5.

5. Summary. From the limited amount of data presented no conclusion of wide application can be drawn; but so far as the data obtain, the following points will be noted.

1. The results are a strong confirmation of Bleininger's[2] con-

[2] Orig. Com. 8th Intern. Congress Appl. Chem., 5, 17–32; *Chem. Absts.* 6, 3170.


Trans. Am. Cer. Soc. Vol. XV
Fig. 1.
Kerr & Fulton
TENNESSEE BALL CLAY NO. 3.
Relation between
Volume Shrinkage and
Percent Water Used
Volume Shrinkage — Percent Wet Volume
Percent Water Used
32
28
24
20
36
40
44
48
52
56

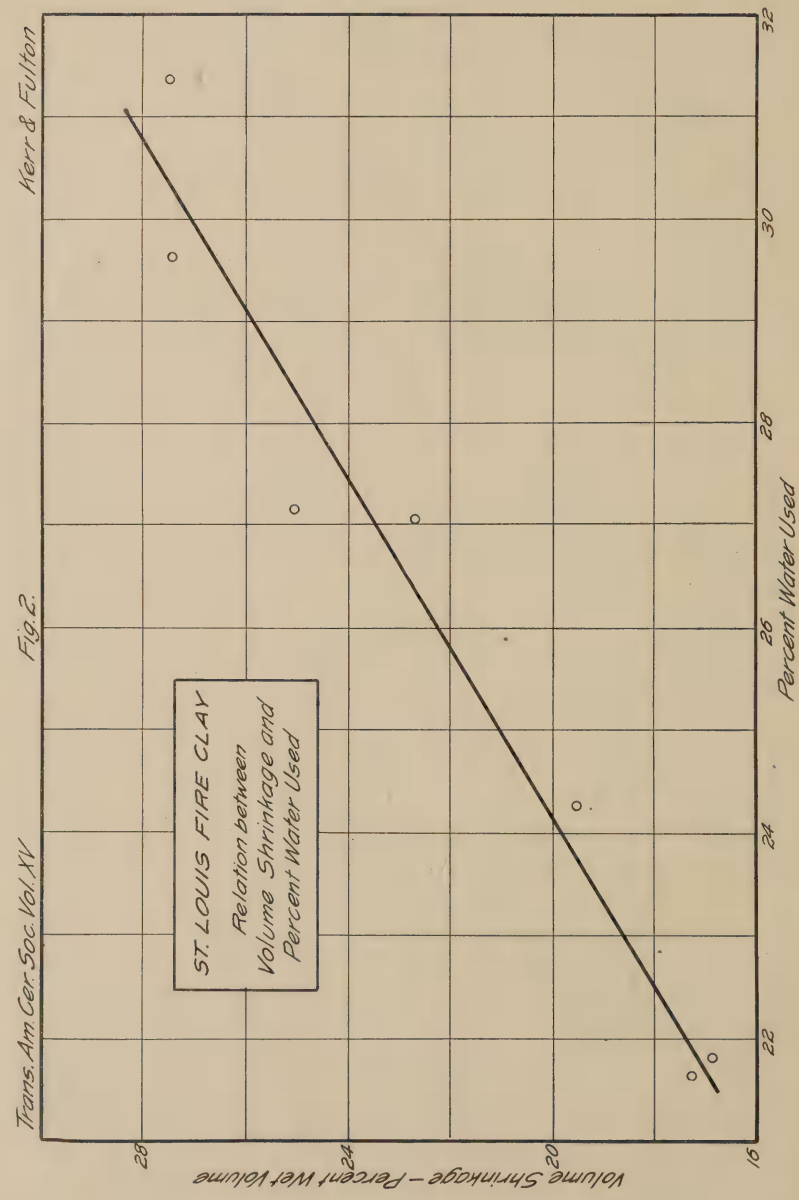

Trans. Am Cer. Soc. Vol. XV
Fig. 2.
Kerr & Fulton
ST. LOUIS FIRE CLAY
Relation between
Volume Shrinkage and
Percent Water Used
Volume Shrinkage – Percent Wet Volume
Percent Water Used
16
20
24
28
22
26
30
32

TABLE 5—ST. LOUIS FIRE CLAY

Volume Shrinkage Percent

	NaCl	Na_2CO_3	NaOH	$CaCl_2$	$BaCl_2$ $2H_2O$	Al_2Cl_6 $12H_2O$
0.000	22.08	21.32	22.42	22.67	21.40	——
0.015	22.38	19.95	20.99	20.94	20.46	21.14
0.025	22.21	19.40	20.45	21.46	20.08	20.73
0.035	21.96	19.34	19.50	20.69	20.75	20.89
0.050	21.43	20.55	20.07	21.18	20.35	21.22
0.10	21.53	20.61	20.09	20.77	21.29	22.39
0.25	21.14	20.05	21.13	20.05	21.10	20.47
0.50	20.77	20.40	20.50	20.49	20.57	20.75
0.75	20.99	20.48	21.56	20.75	20.31	20.65
1.00	19.68	19.82	21.19	20.49	20.73	20.40
1.50	20.73	20.31	21.35	21.23	20.81	19.40
2.00	19.11	19.71	21.61	21.65	20.77	20.59

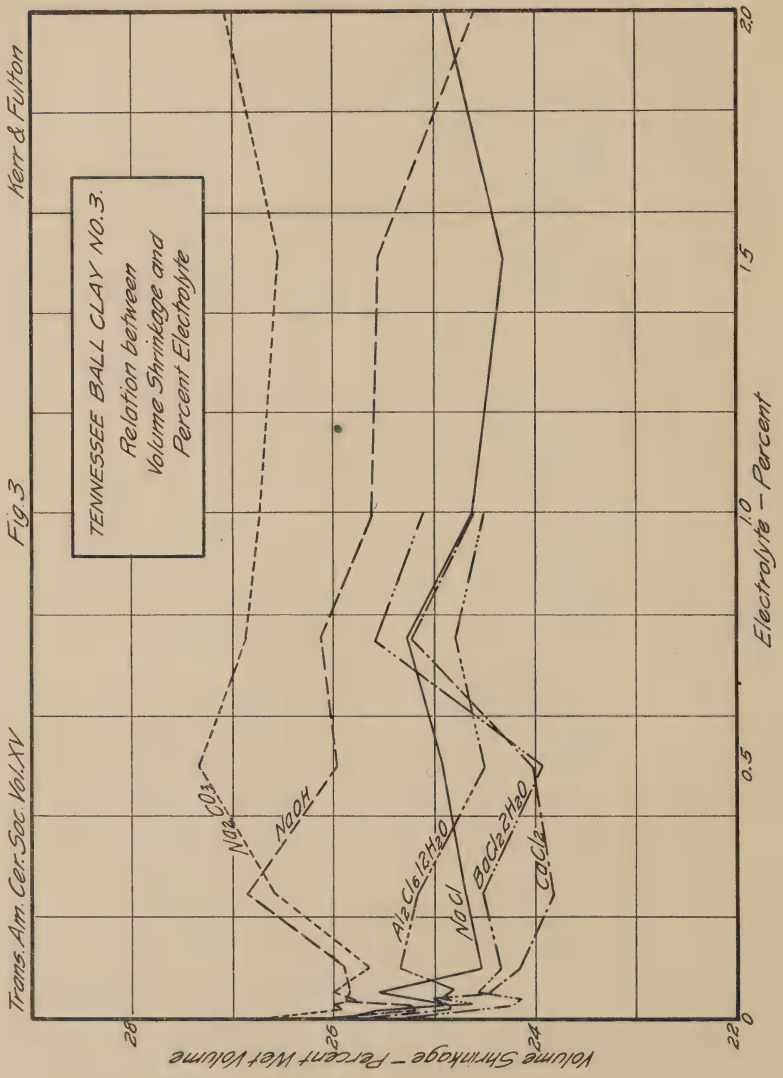
TABLE 6—ST. LOUIS FIRE CLAY

Amounts of Water Used in Tests of Table 5

	NaCl	Na_2CO_3	NaOH	$CaCl_2$	$BaCl_2$ $2H_2O$	Al_2Cl_6 $12H_2O$
0.000	25.9	25.9	25.9	25.9	25.9	25.9
0.015	26.8	25.7	24.8	24.4	25.9	25.3
0.025	25.9	25.1	24.4	24.8	25.5	25.1
0.035	25.5	25.3	23.5	24.4	25.1	25.5
0.050	25.1	26.1	24.8	25.5	25.5	25.5
0.10	25.5	25.3	24.8	25.1	25.7	25.7
0.25	26.3	24.8	26.1	25.1	26.8	25.3
0.50	26.1	24.2	26.1	25.5	26.6	26.3
0.75	26.8	25.5	27.9	25.3	25.9	26.3
1.00	25.5	24.2	26.8	25.5	25.9	26.8
1.50	25.7	25.1	27.0	25.9	26.6	27.0
2.00	25.5	24.8	27.4	26.3	26.1	27.6

clusion, that there is very unstable equilibrium in these clay slips which is greatly affected by the addition of very small amounts of electrolytes.

2. The effect of the electrolyte is not confined to changing the amount of water necessary to produce plasticity. If variations in volume shrinkage due to differing amounts of water be allowed for, there still remain other variations (many of them great) due to other roles of the electrolyte.


Trans. Am. Cer. Soc. Vol. XV
Fig. 3
Kerr & Fulton
TENNESSEE BALL CLAY NO. 3.
Relation between
Volume Shrinkage and
Percent Electrolyte
Volume Shrinkage – Percent Wet Volume
Electrolyte – Percent
Na2CO3
NaOH
AlCl3.6H2O
NaCl
BaCl2.2H2O
CaCl2
28
26
24
22
0
0.5
1.0
1.5
2.0

Trans. Am. Cer. Soc. Vol. XV
Fig. 4.
Kerr & Fulton
ST. LOUIS FIRE CLAY
Relation between
Volume Shrinkage
and Percent Electrolyte
NaCl
BaCl2 2H2O
NaOH
Al2Cl6 12H2O
CaCl2
Na2CO3
Volume Shrinkage — Percent Wet Volume
Electrolyte — Percent
22
21
20
19
0
0.5
1.0
1.5
2.0

3. The variations in volume shrinkage due to differences in the amounts of water used are apparently not dependent upon and not directly connected with other variations in volume shrinkage due to other roles of the electrolyte.

DISCUSSION

Mr. Kerr: This work is not given as a complete study, but simply to add collaborative data. We have everywhere checked Prof. Bleininger's conclusion that great instability exists in these clay slips so that the addition of very small amounts of electrolytes produce profound changes That is shown very plainly in the curves given. The addition of fifteen thousandths of one per-cent of sodium carbonate produced that immense drop in the sodium carbonate curve, and in all the curves we found the same tendency to very rapid fluctuation with a very small addition of electrolyte; that seemed to be very typical and supports entirely Prof. Bleininger's contention.

Mr. Watts: Did you find any difference in the action with different densities of slip?

Mr. Kerr: We did not study that; all of these were bodies mixed to the best working consistency for the individual case. The amounts of water are tabulated in the paper.

THE FUNCTION OF TIME IN THE VITRIFICATION OF CLAYS[1]

BY G. H. BROWN AND G. A. MURRAY, PITTSBURGH, PA.

1. INTRODUCTION

It is a well-known fact that time is an exceedingly important factor in the maturing of clays and bodies. A certain result may be obtained either by the application of a higher intensity of heat for a shorter time or a lower temperature for a longer time. This fact we see constantly illustrated in the firing of all kinds of clay products, the melting of glass, the softening of pyrometric cones, etc. Yet there are definite thermal limits to which such relations are confined. These correspond to the lowest temperature at which partial softening, which is a necessary condition of vitrification, can take place.

It should be recognized also that the closing up of the pore system is not entirely due to the action of fluxes, part of it is undoubtedly to be ascribed to the contraction of the colloidal portion of clays, since condensation is typical of many amorphous bodies such as pure alumina, magnesia, zirconia, etc. We have however no means of differentiating between the two kinds of contraction. In impure clays and in materials like shales this condensation is not marked. The colloidal material causing the contraction in question is active in this direction only as long as it persists in this form. As soon as it becomes transformed into the crystalline state or becomes "set," due to the action of fluxes, it ceases to show this phenomenon. The addition of colloidal silicic acid to clay, therefore, does not increase the shrinkage for the reason that upon loss of the chemical water and further ignition the substance becomes transformed into crystalline silica.

2. DESCRIPTION OF WORK

The plan of the present work followed was that of Bleininger and Boys, consisting in heating clays to their maturing temperatures at definite rates and comparing the heat effect by means of

[1] By permission of the Director, Bureau of Standards.

porosity and shrinkage determinations. Six clays were studied in this connection which were as follows.

1. A paving brick shale from Streator, Illinois (Lab. No. 30).
2. A paving brick shale from Cleveland, Ohio (No. 16).
3. A paving brick shale from Canton, Ohio (No. 35).
4. A red burning surface clay from Urbana, Ill. (No. 37).
5. A calcareous, buff burning surface clay, Heron Lake, Minn. (No. 14).
6. A No. 3 fire clay, West Decatur Pa. (No. 12).

The chemical analyses of these materials are given in Table I.

TABLE I

CLAY NO.	1	2	3	4	5	6
SiO_2	58.98	57.75	57.30	73.06	55.22	60.41
Al_2O_3	19.59	22.30	24.31	12.36	11.88	19.49
Fe_2O_3	7.46	6.51	3.30	2.26	4.37	2.07
TiO_2	0.76	0.86	0.98	0.78	0.95	1.98
CaO	0.95	1.75	0.58	0.83	8.62	0.42
MgO	1.55	0.08	2.19	1.27	2.66	0.56
Na_2O	1.08	0.81	1.11	0.97	0.80	1.35
K_2O	2.27	3.43	2.43	2.10	1.48	2.76
Loss at 100°	0.29	0.78	0.98	1.34	——	0.48
Loss on ignition	7.18	6.01	6.93	5.11	13.94	10.84
Total	100.11	100.28	100.11	100.08	99.92	100.36

The clays were ground in the dry pan, screened and tempered in the pan to a homogeneous mass of good plastic consistency. These plastic batches were then put through a small auger machine and pressed into a cylindrical column, $2\frac{3}{4}$ inches in diameter. This was then cut into discs, 1 inch in thickness. After drying the specimens, they were fired in a gas fired kiln to 850°C. This temperature was maintained until the clays were fully oxidized.

The volume of the pieces was then determined by means of the Seger voluminometer, as was the porosity. Following this they were thoroughly dried and subjected to firings arranged according to definite schedules. The burning was carried on in a large downdraft test kiln, fired with natural gas. Accurate temperature control was maintained by means of a recording Siemens-

Halske pyrometer, checked by readings from another thermocouple connected to a non-recording millivoltmeter. The draft was regulated according to a delicate manometer and a recording carbon dioxide apparatus. Pyrometric cones were placed in the kiln for each burn.

Owing to the precautions taken it was quite an easy matter to follow the straight lines of the time-temperature schedules with considerale accuracy. The rates of firing as first planned were as follows:

Temperature increase in °C. per hour.....	50	42.5	25	27.5	20
Duration of burn in hours.....	24	26	32	44	60

It was found, however, after making a number of runs, that this arrangement was unsatisfactory owing to the short intervals in the duration of the burns, and for this reason a second schedule was adopted:

Temperature increase in °C. per hour.....	50	25	16.6	12.5
Duration of burn in hours.....	24	48	72	96

At intervals of 20° during the vitrification stage of the clays two discs of every clay were drawn through an opening in the kiln door and allowed to cool in a small pot furnace, previously heated to about 800°. Determinations of the volume, porosity and apparent specific gravity were made on each disc.

3. DISCUSSION OF RESULTS

A. CLAY NO. 1.

In Table II the results of the porosity and shrinkage measurements are compiled which are plotted in the diagrams of Figures 1 and 2. From these the following iso-porosity relations are found to hold:

Porosity percent	*Temperature reached degrees*	*Time hours*
20	1070	69
	1090	39
	1110	26
15	1090	75
	1110	42.5
	1130	18
10	1110	80
	1130	47

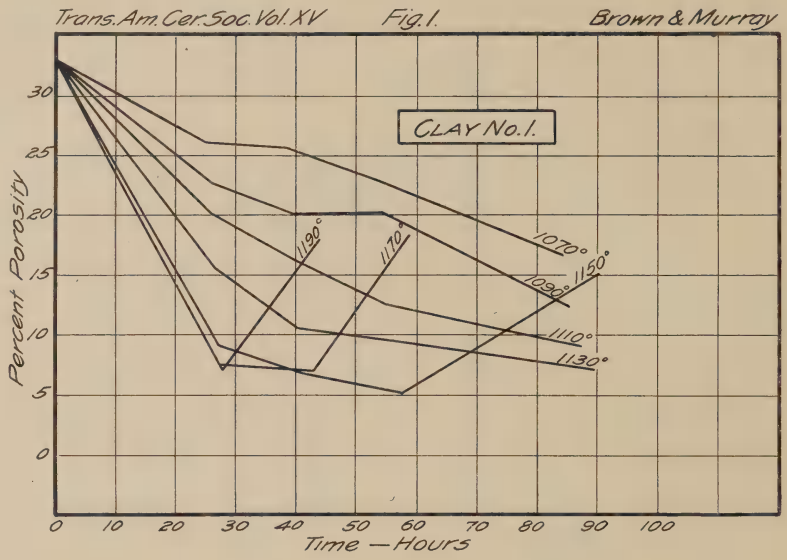

Trans. Am. Cer. Soc. Vol. XV
Fig. 1.
Brown & Murray
CLAY No. 1.
Percent Porosity
0
5
10
15
20
25
30
1190°
1170°
1070°
1150°
1090°
1110°
1130°
0 10 20 30 40 50 60 70 80 90 100
Time — Hours

Fig. 2.

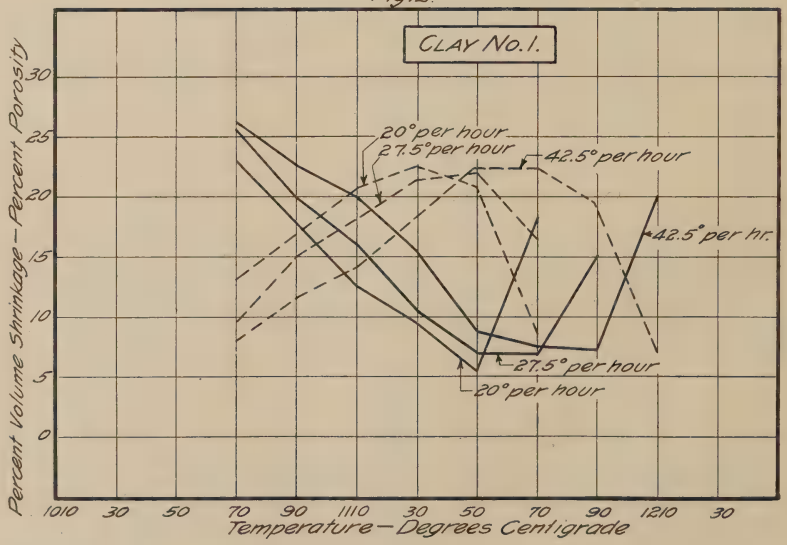

CLAY No. 1.
Percent Volume Shrinkage — Percent Porosity
0
5
10
15
20
25
30
20° per hour
27.5° per hour
42.5° per hour
42.5° per hr.
27.5° per hour
20° per hour
1010 30 50 70 90 1110 30 50 70 90 1210 30
Temperature — Degrees Centigrade

TABLE II—CLAY NO. 1 (LAB. NO. 30)

TEMP. REACHED °C.	PERCENT POROSITY				PERCENT VOLUME SHRINKAGE			
	Rate of heating °C per hour							
	42.5	27.5	20.	12.5	42.5	27.5	20.	12.6
1070	26.1	25.6	22.9	16.8	7.8	9.6	13.0	17.7
1090	22.6	19.9	20.6	12.5	11.6	14.8	14.6	19.7
1110	20.1	15.8	12.3	9.2	13.9	17.9	20.2	21.3
1130	15.5	10.5	9.5	7.3	18.4	21.4	22.2	16.9
1150	8.9	6.9	5.5	15.4	22.2	22.0	20.9	12.6
1170	7.6	6.8	18.6	20.5	22.2	16.6	8.0	9.2
1190	7.3	17.9	23.7	....	19.4	6.8	3.8	1.8
1210	19.8	21.3	....	....	6.8	2.7	....	....

Overburning begins at 1150° after 57.5 hours, at 1170° after 43 hours and 1190° after 28 hours. A state of equilibrium was not reached in any case since the curves for the temperature 1070° to 1130° still show a decided slope, and it is reasonable to suppose that the minimum porosity would be reached at 1130°, 1110° and perhaps 1090° after increasing periods of time. The suddenness of overburning is somewhat surprising, and it is evident that the rapidity of the vesicular structure development is both a function of the temperature and rate of firing. Overburning is not merely a question of temperature but of time as well, since at the same temperature both a sound or a poor structure may be obtained depending simply upon the rate of firing. For the clay in question it would undoubtedly be better to complete the burning at 1130° at a slow rate of heating. The practice of "soaking" a kiln therefore is of value, provided that the heat treatment is well within the critical temperature range.

The diagram of Figure 2 makes possible the comparison of the shrinkage and porosity curves. The peculiar fact is at once noted that the points of minimum porosity and maximum shrinkage are not coincident. Thus the curve representing the heating rate of 20° per hour shows maximum shrinkage at 1130° and minimum porosity at 1150°. The same thing holds also for the other curves. This tends to show that vesicular structure exists and that closed cavities are formed into which water cannot penetrate and which for this reason escapes observation in the usual po-

rosity determination. The shrinkage curves again indicate the fact that slow firing matures the clay at a lower temperature than more rapid heating, since the 20° rate results in maximum condensation at 1130°, while the others correspond to 1150° and 1170°, respectively.

By calculating the porosity decrease, expressed in percent, per hour, and comparing this with the rate of firing, the speeds of vitrification are computed. These are shown in Figure 3. As is to be expected, the greatest speed of contraction is obtained by the most rapid heating. As the lower porosities are reached the rate of vitrification diminishes. The rate of contraction, however, is not a simple function of the heat increment, but is complicated by the degree of viscosity of the softening mass and is in part rendered unreal by the development of vesicular pore space. It is obvious from the results obtained that the rate of 42.5° per hour is entirely too fast for obtaining a sound structure. Slow burning to the minimum temperature will produce the best results with this clay.

B. CLAY NO. 2.

The numerical results of the porosity and shrinkage determinations are collected in Table III and the diagram of the porosity-

TABLE III—CLAY NO. 2 (LAB. NO. 16)

TEMP. REACHED °C.	PERCENT POROSITY				PERCENT VOLUME SHRINKAGE			
	Rates of heating, °C per hour							
	42.5	27.5	20.0	12.5	42.5	27.5	20.0	12.5
950	22.6	22.2	21.8	21.7	0.4	0.8	0.9	1.0
970	22.8	22.6	21.2	21.2	1.1	0.3	1.1	2.6
990	21.4	21.7	19.8	17.6	1.7	0.4	4.4	5.3
1010	20.0	....	18.3	16.1	2.8	2.5	6.7	8.3
1030	17.2	19.6	14.2	14.0	4.8	3.9	8.3	9.6
1050	14.9	16.3	10.0	6.9	8.4	7.6	11.5	15.5
1070	9.1	9.8	5.9	3.3	12.8	12.4	15.9	12.6
1090	8.1	5.2	4.9	2.6	14.6	14.4	9.8	....
1110	4.7	3.4	3.1	10.5	15.2	12.6	....	....
1130	3.1	10.1	19.8	....	9.9	....	....	....
1150	21.3	....	....	....	....	....	....	....

time-temperature relations is given in Figure 4. Here some of the iso-porosity equivalents are as follows:

Porosity percent	*Temperatnre reached degrees*	*Time hours*
20	990	49
	1010	24
15	1030	45
	1050	24.5
9	1050	62
	1070	26
7.5	1050	77
	1070	40
	1090	29
4.5	1070	70
	1090	59
	1110	26.5

It is observed that overfiring occurs at 1130° after 41, and at 1110° after 66 hours. The maximum density is obtained after 86.5 hours at 1090° and this temperature is the highest for safe burning, provided the rate of firing is not too slow. The effect of the speed of heating is brought out in the diagram of Figure 5 in which the volume shrinkages are plotted. The point of maximum shrinkage is reached at 1050°, firing at the rate of 12.5° per hour, at 1070°, with a rise of 20° per hour, at 1090°, with 27.5° per hour and at 1110°, with 42.5 per hour, thus verifying the statement that the slower the rate of firing the lower the temperature at which a given amount of heat work is accomplished. Attempts to work out a general relation between the rate of heating temperature and porosity were unsatisfactory. Owing to the fact that the maximum shrinkages for the different rates of heating are sufficiently close together, corresponding to 15 ± 1 percent, these values have been taken to be equivalent.

Plotting the rates of heating against the temperatures at which maximum shrinkage has been reached the curve shown in Figure 6 is obtained, which illustrates the relation of the maturing temperature to the rate of firing. Between the rates 12.5° and 27.7° per hour the temperature increases practically linearly, but beyond 30° per hour the trend of the curve is towards a limiting value.

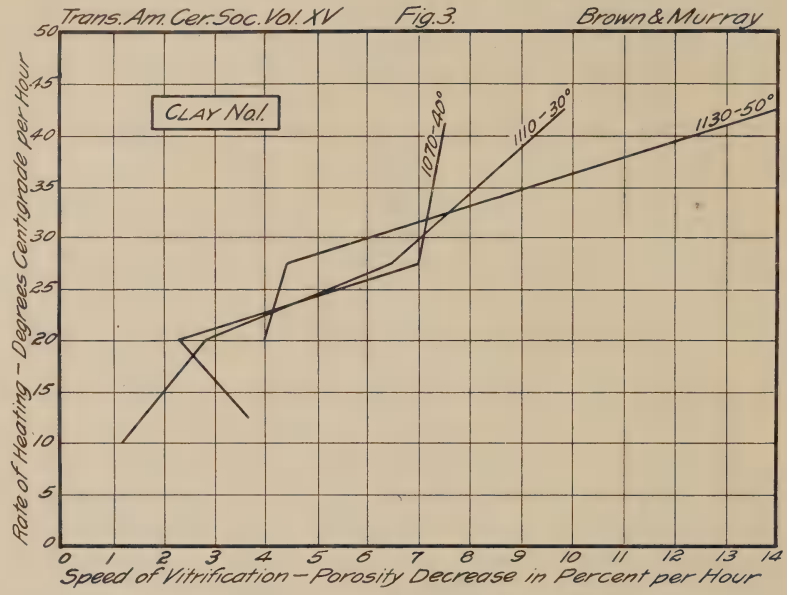
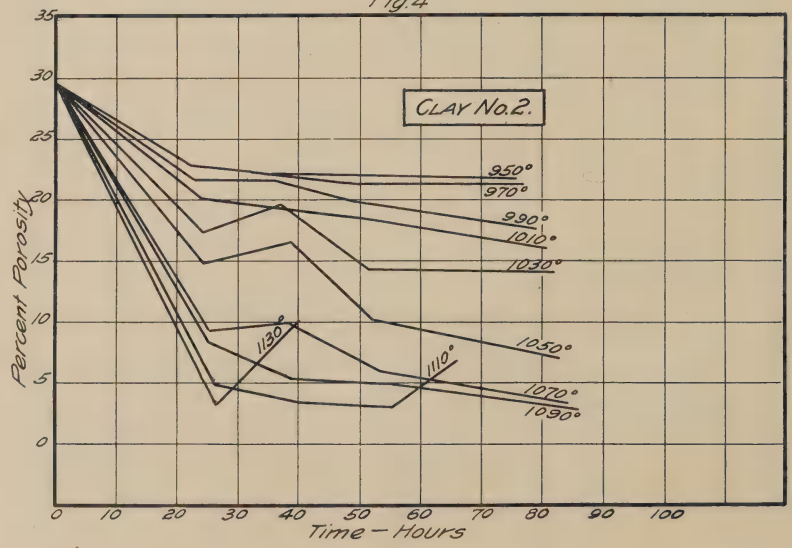

Trans. Am. Cer. Soc. Vol. XV
Fig. 3.
Brown & Murray
CLAY No. 1.
1070-40°
1110-30°
1130-50°
Rate of Heating – Degrees Centigrade per Hour
Speed of Vitrification – Porosity Decrease in Percent per Hour

Fig. 4


CLAY No. 2.
950°
970°
990°
1010°
1030°
1050°
1070°
1090°
1110°
1130°
Percent Porosity
Time – Hours

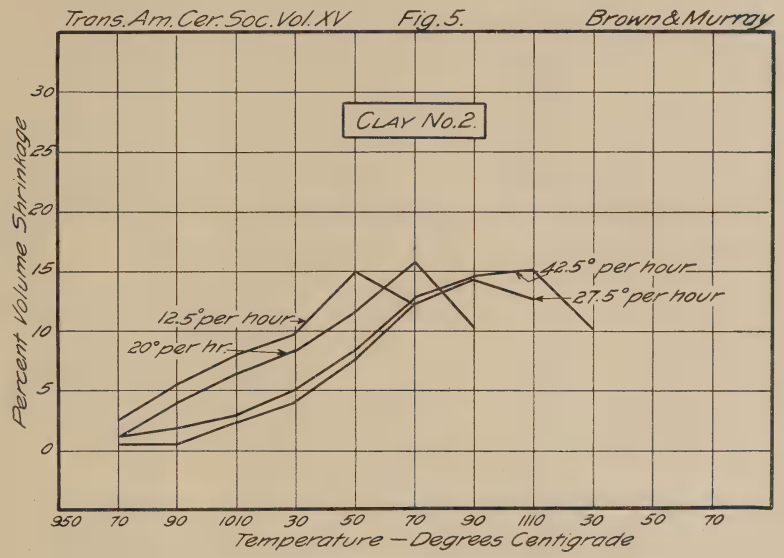
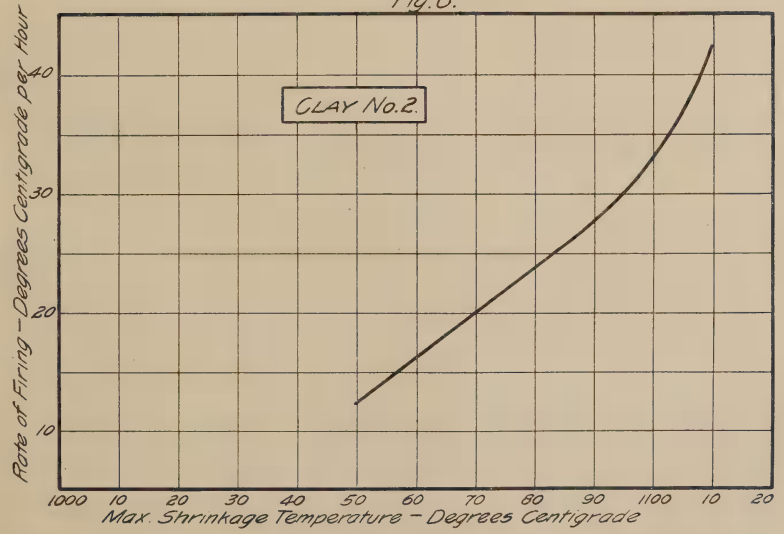

Trans. Am. Cer. Soc. Vol. XV
Fig. 5.
Brown & Murray
CLAY No. 2.
12.5° per hour
20° per hr.
42.5° per hour
27.5° per hour
Percent Volume Shrinkage
0
5
10
15
20
25
30
950 70 90 1010 30 50 70 90 1110 30 50 70
Temperature — Degrees Centigrade

Fig. 6.


CLAY No. 2.
Rate of Firing — Degrees Centigrade per Hour
10
20
30
40
1000 10 20 30 40 50 60 70 80 90 1100 10 20
Max. Shrinkage Temperature — Degrees Centigrade

The speeds of vitrification at the different temperatures and rates of heating are presented in the diagram of Figure 7, from which it is apparent that the maximum rate of condensation is obtained between 1050° to 1070°, with a rate of heating of 42.5° per hour.

C. CLAY NO. 3.

Table IV contains the values obtained in the porosity and shrinkage determinations which are shown graphically in Figures 8 and 9. Some of the iso-porosity relations are as follows:

Porosity percent	*Temperature reached degrees*	*Time hours*
14	1090	43.5
	1110	22.0
10	1090	61
	1110	34
7	1110	52
	1130	22.5
5	1110	64
	1130	33
	1150	26.5
3	1130	43.5
	1150	35
	1170	23.5

The fact that 1170° is too high a finishing temperature is shown by the fact that vesicular structure is produced when the firing is carried on at a rate so high this temperature is reached after 47 hours. The excellent firing behavior of this shale is shown by the

TABLE IV—CLAY NO. 3 (LAB. NO. 35)

TEMP. REACHED °C.	PERCENT POROSITY				PERCENT VOLUME SHRINKAGE			
	Rates of heating, °C per hour							
	50	25	16.66	12.5	50	25	16.66	12.5
1050	21.4	21.6	20.0	18.9	18.1	18.4	21.1	20.3
1070	20.9	15.2	12.7	14.6	18.9	23.3	25.2	24.2
1090	16.8	11.8	....	9.7	23.0	26.9	28.1	27.5
1110	11.8	8.2	4.5	3.5	26.8	29.0	29.4	28.5
1130	6.8	2.5	1.1	0.7	28.0	29.1	29.3	28.0
1150	5.8	0.3	0.6	0.7	29.0	28.7	27.5	26.4
1170	2.8	0.8	22.1	2.7	25.0	25.5	18.2	20.9
1190	11.2	12.9	....	....	17.8	18.0	12.4	18.7

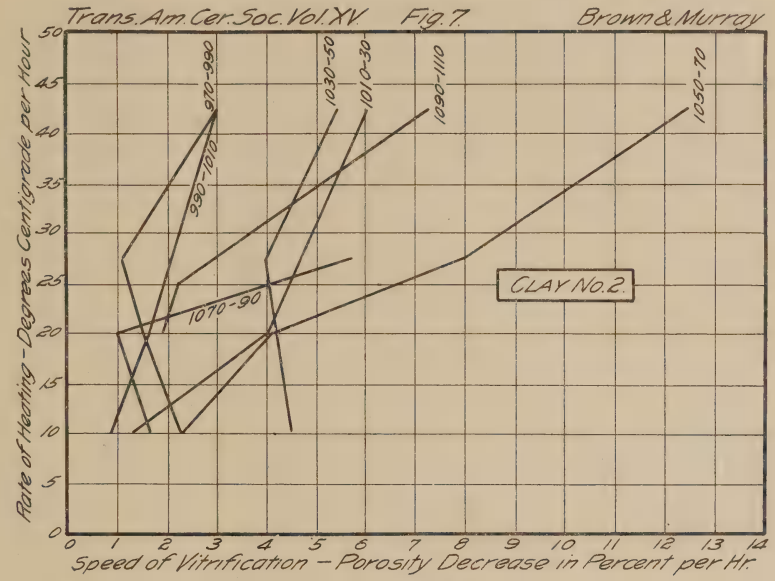
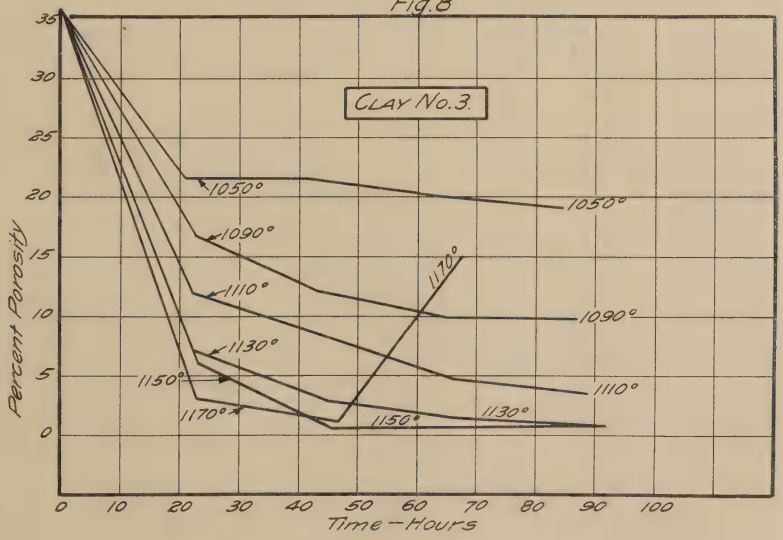

Trans. Am. Cer. Soc. Vol. XV. Fig. 7 Brown & Murray
Rate of Heating - Degrees Centigrade per Hour
Speed of Vitrification - Porosity Decrease in Percent per Hr.
970-990
1030-50
1010-30
1090-1110
1050-70
930-1010
1070-90
CLAY No. 2.

Fig. 8


CLAY No. 3.
Percent Porosity
Time - Hours
1050°
1090°
1110°
1130°
1150°
1170°

steady decrease in porosity indicated by the 1130° and 1150° curves and the long range during which the minimum porosity is maintained. Incidentally the fact is brought out that in the testing of clays the time of burning should not be too short even for small specimens. The rapid tests frequently made in such work are for this reason open to criticism. The longer the time of burning is taken so that it approaches the rates of commercial kiln operation the more useful will be the results obtained with reference to their industrial application. The diagram of Figure 8 shows also that complete vitrification is reached at 1130° and at 1150°, the difference being only the somewhat longer time required with the lower temperature. From the diagram of Figure 9 it appears that the points of maximum shrinkage practically agree for the rates of heating of 12.5, 16.66 and 25° per hour at 1110°, while for the 50° rate the same point is reached only at 1150°. The maximum speed of vitrification for this shale is reached with the heating rate of 50° per hour, between 1070–90° and 1110–30° and corresponds to 10.25 percent porosity per hour.

D. CLAY NO. 4.

The numerical data relating to the porosity and shrinkage determinations are compiled in Table V, and the graphical presentation is given in Figures 10 and 11. A number of the iso-porosity values are collected as follows:

TABLE V—CLAY NO. 4 (LAB. NO. 37)

TEMP. REACHED °C.	PERCENT POROSITY				PERCENT VOLUME SHRINKAGE			
	Rates of heating, °C per hour							
	50.0	25.0	16.66	12.5	50.0	25.0	16.66	12.5
1030	30.7	28.8	29.0	....	5.0	8.7	6.1	....
1050	20.1	23.9	24.0	22.2	7.0	13.0	13.4	15.1
1070	22.4	18.8	13.4	14.4	14.8	19.0	19.6	22.4
1090	21.3	10.9	8.0	10.2	15.8	24.6	25.8	26.3
1110	9.9	8.2	4.5	4.0	24.8	27.4	27.2	27.2
1130	7.6	2.0	0.1	0.9	27.0	26.1	25.2	25.3
1150	3.2	1.0	2.3	4.4	26.1	24.4	17.7	19.7
1170	3.4	1.9	28.5	24.3	17.3	16.9	....	....
1190	24.3	31.4	....	....	....	....	....	....

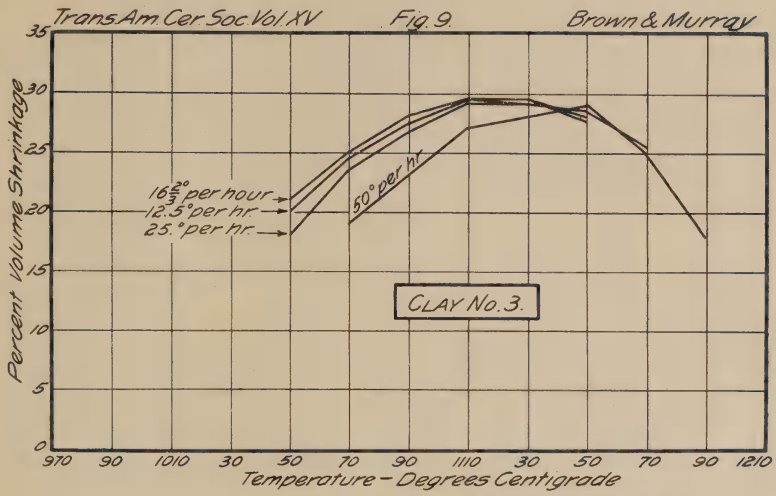
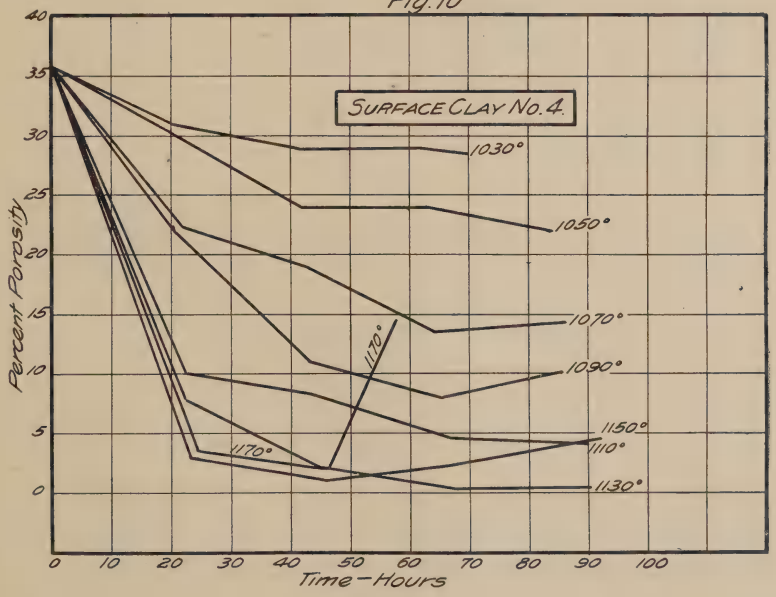

Trans. Am. Cer. Soc. Vol. XV
Fig. 9.
Brown & Murray
Percent Volume Shrinkage
Temperature – Degrees Centigrade
16⅔° per hour
12.5° per hr.
25.° per hr.
50° per hr.
CLAY No. 3.

Fig. 10


Percent Porosity
Time – Hours
SURFACE CLAY No. 4.
1030°
1050°
1070°
1090°
1150°
1110°
1130°
1170°
1170°

Porosity *percent*	*Temperature reached* *degrees*	*Time* *hours*
20	1070	36
	1090	24.5
15	1070	58
	1090	35
9.75	1090	51
	1110	22
7.5	1110	49
	1130	23.5
5	1110	63.5
	1130	34.0

Both the 1150° and 1170° curves show evidence of overburning.

Like with the preceding clay the point of maximum shrinkage (Fig. 11) coincides for three rates of heating, but is 20° higher on the 50° curve. From this it appears that the rate of firing could be at least 25° per hour without displacing the point of maximum shrinkage.

The maximum safe burning temperature is about 1130°. The speed of vitrification was calculated to be 28.3 percent porosity decrease per hour between 1090° and 1110°, for the heating rate of 50° per hour. With a temperature increase of 25° per hour the maximum speed of vitrification, 9.8 percent porosity decrease per hour, is obtained between 1070 to 1090°.

E. CLAY NO. 5.

Table VI contains the porosity and shrinkage values obtained for this material which are reproduced diagrammatically in Figures 12 and 13.

TABLE VI—CLAY NO. 5 (LAB NO. 14)

TEMP. REACHED °C.	PERCENT POROSITY				PERCENT VOLUME SHRINKRGE			
	Rates of heating, °C per honr							
	50.0	25.0	16.66	12.5	50.0	25.0	16.66	12.5
990	41.3	40.2	39.9	41.9	1.5	1.1	1.8	1.3
1010	41.0	40.3	39.7	42.0	1.7	2.2	1.4	0.7
1030	40.6	38.4	36.4	38.8	2.5	3.3	3.3	3.2
1050	38.1	36.3	31.9	31.1	5.5	7.9	8.5	13.2
1070	33.1	5.4	0.0	0.4	10.5	30.0	33.6	32.9
1090	4.6	0.2	0.0	0.0	30.3	33.8	30.3	32.0
1110	0.0	0.2	0.0	0.0	31.1	27.9	....	....

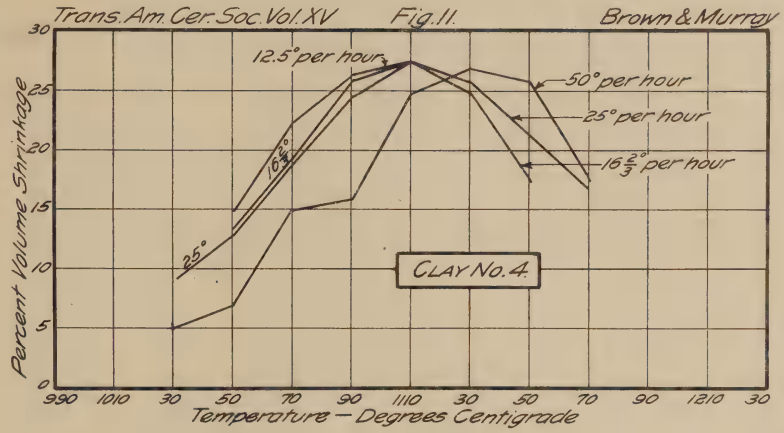
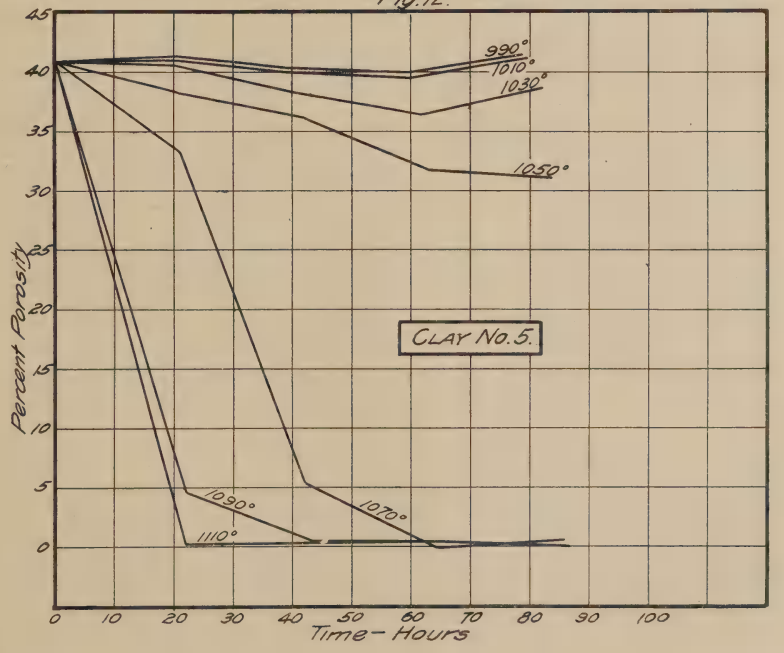

Trans. Am. Cer. Soc. Vol. XV
Fig. 11.
Brown & Murray
Percent Volume Shrinkage
Temperature — Degrees Centigrade
12.5° per hour
50° per hour
25° per hour
16⅔° per hour
25°
CLAY No. 4.
990
1010
1110
1210

Fig. 12.


Percent Porosity
Time — Hours
990°
1010°
1030°
1050°
1090°
1110°
1070°
CLAY No. 5.

Some of the iso-porosity relations are as follows:

Porosity	*Temperature reached*	*Time*
percent	*degrees*	*hours*
37.5	1030	49
	1050	28
32.5	1050	60
	1070	22
4.5	1070	46
	1090	22
2.5	1070	54
	1090	32.5

The diagram of Figure 12 shows strikingly the typical behavior of calcareous clays, in which vitrification takes place rapidly, and a short temperature interval separates the open from the dense structure. This example illustrates also the influence of the composition upon the time-temperature relation and proves the impossibility of calculating a factor which does not take into account the specific decrease in viscosity due to the material itself.

Upon inspection of Figure 13 it is noted that this clay is influenced appreciably by the rate of firing. While the maximum shrinkage points of the curves, representing the 12.5° and 16.6° per hour rates coincide at 1070°, the corresponding point of the 25° curve is found to be at 1090° and of the 50° rate at 1110°. Calculating the speed of vitrification in percent porosity decrease per hour the maximum value was found with the heating rate of 50° per hour and corresponded to 71 percent between 1070° to 1090°, thus illustrating the rapidity of contraction. During the temperature interval 1050° to 1070° the maximum speed was found in connection with the 25° rate and amounted to 38.2 per cent.

F. CLAY NO. 6.

Table VII contains the numerical results obtained in connection with this clay. The diagrams of Figures 14 and 15 present these in graphical form. Some of the iso-porosity relations are as follows:

Porosity *percent*	*Temperature reached* *degrees*	*Time* *hours*
16	1090	35
	1110	25
14	1090	61
	1110	38
12	1110	50
	1130	25
10	1110	64
	1130	39
8	1130	55
	1150	23
5	1130	85
	1150	48

The evidence of overburning is shown and the clay becomes dense without any apparent irregularities. For this reason this material, may be burned safely with considerable rapidity to the temperature of 1170° and even higher. The conditions therefore are almost ideal in this respect. It will also be noted that the progress of contraction is gradual as is indicated by the regular intervals between the curves. A definite porosity limit is reached in the curves up to 1130°, showing that an equilibrium was obtained as far as the amount of softened material is concerned.

Referring to Figure 15, the maximum shrinkage takes place at 1150° with the rate of heating corresponding to 12.5° per hour, a

TABLE VII—CLAY NO. 6 (LAB. NO. 12)

TEMP. REACHED °C.	PERCENT POROSITY				PERCENT VOLUME SHRINKAGE			
	Rates of heating, °C per hour							
	50.0	25.0	16.66	12.5	50.0	25.0	16.66	12.5
1030	24.5	23.3	23.6	23.6	12.0	13.3	12.8	12.8
1050	22.9	20.8	19.5	19.2	13.9	15.4	16.9	16.5
1070	22.6	17.9	15.1	16.8	15.5	19.1	18.1	18.9
1090	17.6	14.9	13.9	13.9	18.4	21.8	21.3	21.6
1110	16.2	12.8	9.3	9.5	20.9	23.9	24.8	23.7
1130	11.7	9.0	6.4	4.5	24.4	24.6	24.7	24.8
1150	8.1	5.5	1.2	0.7	25.3	25.0	25.8	25.4
1170	....	1.5	1.3	0.5	....	26.7	24.5	25.5
1190	1.5	0.5	1.6	0.3	25.8	26.2	22.7	25.3
1210	....	....	....	....	24.9	25.3	....	24.1

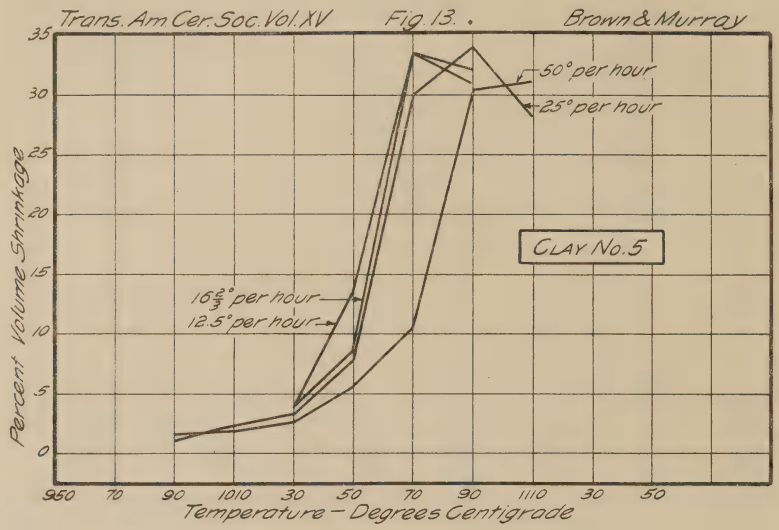
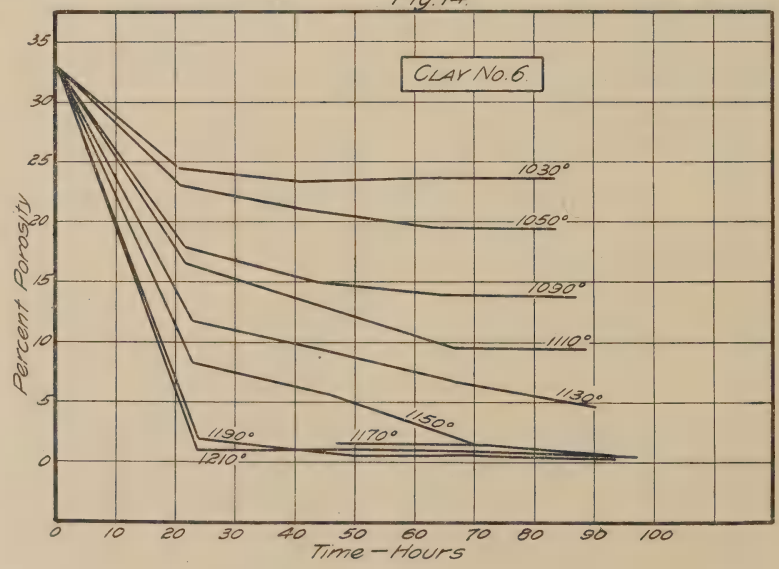

Trans. Am Cer. Soc. Vol. XV
Fig. 13.
Brown & Murray
50° per hour
25° per hour
16⅔° per hour
12.5° per hour
CLAY No. 5
Percent Volume Shrinkage
Temperature – Degrees Centigrade

Fig. 14.


CLAY No. 6
1030°
1050°
1090°
1110°
1130°
1150°
1170°
1190°
1210°
Percent Porosity
Time – Hours

lower maximum contraction appears to have been reached at1130°, with 16.6° per hour. The highest shrinkage, 27 percent, is obtained with the 25° rate. Singularly, the maximum contraction for the 50° rate is only 26 percent and is reached at 1190°. These differences, however, are not marked and this clay, more than the others, responds to the time-temperature factor in a regular manner.

The diagram of Figure 16 illustrates the speeds of vitrification and it is apparent that the maximum speed is found in connection with the highest temperature interval and the highest rate. The other temperature intervals however, do not arrange themselves in their order, a fact illustrating again the importance of diverse factors. Regular dependence upon the temperature and rate of heating can exist only when the amount of softening material increases proportionally to the temperature increment. The fulfillment of this condition is quite improbable since the fluxes, even though they dissolve silica and alumina to the possible limit, constantly produce new mixtures of varying viscosity, to say nothing of the physical obstacles encountered in bringing about solution. Hence the total quantity of softening material as well as its properties, change more or less irregularly. The fact that vitrification is retarded towards the completion of vitrification is due in a large measure to the approach towards the final viscosity of the entire body.

4. CONE SOFTENING TEMPERATURES

In carrying out the burning experiments described, at regular prescribed rates of heating an opportunity was offered to compare the softening temperatures of the cones with reference to the time effect. The pyrometric cones used were of those manufactured by Prof. Edward Orton, Columbus, Ohio. It is a well known fact that the silicate mixtures making up these pyroscopes do not possess definite melting points but only a softening interval and that the viscosity of the individual compositions is an important factor in determining the point at which the different numbers deform and bend. It is to be expected therefore that the time factor should affect the softening of the cones in a decided manner.

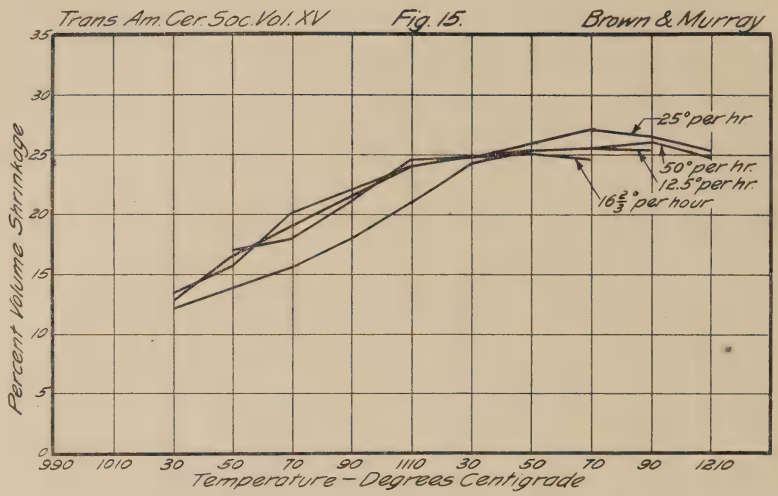
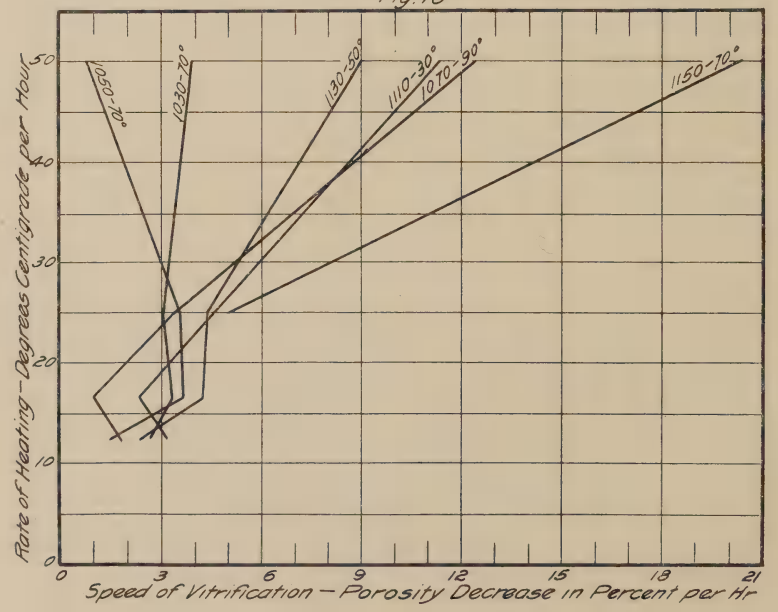

Trans. Am. Cer. Soc. Vol. XV
Fig. 15.
Brown & Murray
Percent Volume Shrinkage
0
5
10
15
20
25
30
35
25° per hr.
50° per hr.
12.5° per hr.
16⅔° per hour.
990
1010
30
50
70
90
1110
30
50
70
90
1210
Temperature – Degrees Centigrade

Fig. 16


Rate of Heating – Degrees Centigrade per Hour
0
10
20
30
40
50
1050-70°
1030-70°
1130-50°
1110-30°
1070-30°
1150-70°
0
3
6
9
12
15
18
21
Speed of Vitrification – Porosity Decrease in Percent per Hr

In Table VIII the softening points of the cones used in the foregoing work are compiled with reference to the rate of heating. In Figure 17 these data are presented graphically. Inspection of the latter shows at once the general tendency to connect high softening points with rapid heating and vice versa. From cone No. 9 to No. 6 inclusive, the lowering of the deformation temperature is quite rapid at first and then slows down decidedly. While the softening point of cone 9 appears to remain constant for the

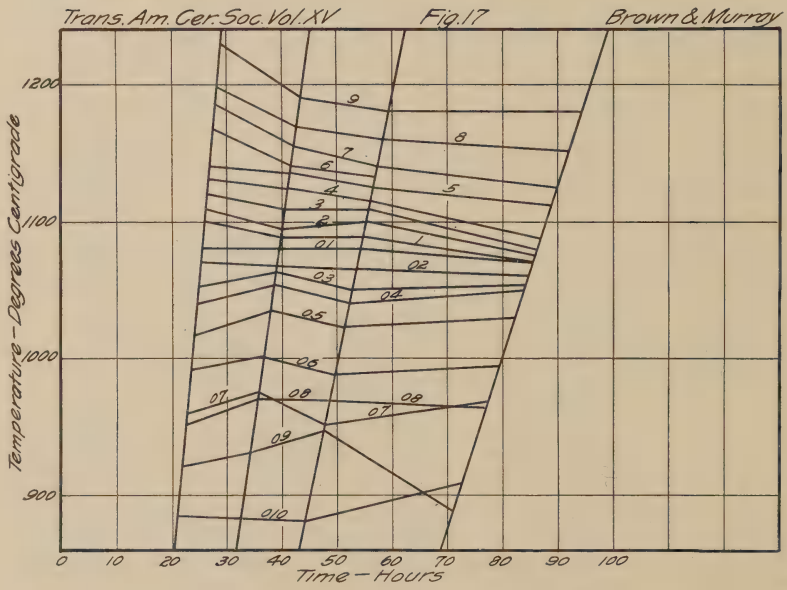
TABLE VIII—SOFTENING POINTS OF CONES °C.

CONES	RATE OF HEATING °C. PER HOUR			
	42.5	27.5	20	12.5
010	885	885	880	910
09	920	930	950	890
08	950	970	970	965
07	960	975	950	970
06	990	1000	990	995
05	1015	1035	1025	1030
04	1040	1055	1040	1045
03	1055	1065	1050	1050
02	1065	1070	1065	1060
01	1080	1080	1080	1070
1	1100	1085	1090	1070
2	1110	1090	1100	1075
3	1120	1110	1110	1080
4	1130	1125	1115	1090
5	1140	1135	1125	1110
6	1170	1140	1135	....
7	1185	1155	1140	1125
8	1200	1170	1160	1150
9	1230	1190	1180	1190

slower rates of heating it continues to become lower for the numbers 8, 7 and 6. Numbers 5 and 4 show a constant lowering of the point in question. With the introduction of ferric oxide in the composition, irregularities begin to occur, although these are not marked until cone No. 03 is reached. Beginning with this number and with the increasing amount of boric acid entering into the mixtures the effect of the heating rate becomes more and more irregular. Thus the rise in the softening temperature of cones

No. 07 and 010 during the longer heating periods is manifestly due to the volatization of boric acid. Reducing conditions or irregular firing cannot be the cause of this behavior since gas analysis showed a large air excess and since the supply of natural gas was under constant control. Upon examination the cones also appeared to be of normal color and showed none of the vesicular structure due to flashing and reducing conditions.

The irregularity of the lower cone numbers is realized by the makers and users and evidently is connected with their composi-



tion. As regards the higher numbers, above No. 03, their regularity of softening and deforming is surprising, knowing the disadvantages under which such a system labors. The results pertaining to cones No. 03 and above have been checked repeatedly, and invariably the softening occurs as is indicated by the curves. These facts should be applied in the use of the cones as they certainly have been helpful in the work of this laboratory. Short burns necessitate the use of higher cone numbers than long burns in accomplishing the same result. Where at the same plant the rate

of firing varies, difficulties are certain to be met with unless the proper corrections are made as has been indicated.

5. SUMMARY

The effect of time in the firing of clay products is of great importance. A rapid rate of firing requires a higher finishing temperature than a slower one.

As a rule the higher the content of fluxes the more marked will be the influence of the time factor.

It is impossible to work out general rules governing the time-temperature relations, owing to the fact that certain specific properties of the clays, such as their viscosity at kiln temperatures, vary widely, according to the composition and physical structure of the different materials. Six typical clays have been studied in this connection and these results may serve as a guide in estimating the time effect upon similar clays.

Vesicular structure is produced not only by excessive temperature but by longer continued burning at lower temperatures as well. The selection of a particular rate of burning must take into account the character of the clay and the size of the product to be fired. For most purposes the rates of firing will be between 10 to 35° C. per hour.

The method of firing at a constant rate cannot be applied to practical work. In conducting clay tests, involving the use of specimens of the size used in this work, a constant rate of heating from 30° to 35° per hour may be maintained after oxidation up to within about 40° of the minimum maturing temperature. From this point on a much slower rate, about 10° per hour, should be employed until the burn is finished. In case reasonable uniformity of temperature cannot be obtained in the kiln, still another change is desirable, consisting in keeping the temperature constant at the minimum maturing point until the clay has reached the desired degree of density.

Unless the conditions of heating are stated, firing results of any kind lose much of their value.

The greater the tendency of a clay to produce vesicular structure the lower should be the burning temperature with a corresponding

increase in time. For this purpose it is necessary to know the temperature limits within which the time factor becomes effective. The speed of vitrification, for a given clay, in general, is greatest at the highest temperature and the most rapid rate of heating. Probably 25° per hour is the maximum rate at which firing should take place under any conditions during vitrification.

The effect of the time-temperature ralations should be studied closely for every clay since only when reliable information concerning this subject is at hand is it possible to exercise complete control of the burning. The importance of such results applied in factory practice cannot be emphasized too much.

The use of pyrometers in plant operation is to be urged most strongly as they afford the only means of controlling the rate of firing. For the establishment of the end point of the burn pyrometric cones, shrinkage and porosity determinations are of value.

In the use of cones the time factor should be taken into account.

DEFORMATION STUDY OF KAOLIN-FELDSPAR MIXTURES

BY HEWITT WILSON, CER.E., COLUMBUS, OHIO.

INTRODUCTION

This study is but one of a large number dealing with feldspars and their impurities.[1] Beside the kaolin impurities, quartz, mica, beryl, together with the various kinds of feldspar, such as potash, soda, albite, orthoclase, anorthite, etc., are found in commercial feldspars in appreciable amounts. As these minerals all have different pyrometrical and chemical behaviors, mixtures of them in the commercial feldspar give results which can not be attributed to pure feldspar alone. In this investigation of the effect of the kaolin impurity, a pure feldspar was synthetically made impure by additions of various percentages of pure kaolin and the deformation properties of these mixtures were studied.

Kaolinization of Feldspar and Significance. The kaolin impurity in most commercial feldspars averages from 1 to 3 percent and usually is the result of the decomposition of more exposed portions of the bed. A description of this "decomposition of feldspar and the recombination of a portion of the decomposition products to form kaolin" is given in Vol. XIV, *T.A.C.S.*, by Watts, "Kaolin Mining in the Appalachian Mountains." Briefly, it is this:

The molecular formula for orthoclase or microcline feldspar is $K_2O \cdot Al_2O_3 \cdot 6SiO_2$. By water solution the K_2O is lost, leaving Al_2O_3 $6SiO_2$ as the insoluble decomposition products. The Al_2O_3 and $2SiO_2$ of this recombine with the absorption of $2H_2O$ to form kaolin leaving 4 molecules of silica as quartz. Thus the presence of kaolin and quartz impurities in a bed of feldspar is partially accounted for.

The increase of the combined water and the decrease of the potash content are thus indicators of the degree of kaolinization. It was found by the curve on page 464, Vol. 14, that as the water

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[1] "Feldspar Studies," by A. S. Watts, Vols. 14 and 15, *T. A. C. S.*

content increases, the deformation temperature also increases. By plotting the water alkali curve along side this other, a corresponding deformation temperature can be obtained for each percentage of alkali in the feldspar. We, therefore, may say that generally, the more kaolinized is the feldspar, i.e., the higher the water and lower the alkali content, the higher will be the deformation temperature. However, when the feldspar contains less than 16 percent kaolin, it has been found that there are indications of the formation of an eutectic, so that the rise of the deformation temperature is not as rapid as with higher percentages of kaolin.

Purpose. To determine in kaolin-feldspar mixtures,

1. The relative deformation;
2. The rate of deformation;
3. Deformation eutectics or compounds;
4. The effect of different sizes of grain of kaolin on the deformation;
5. Deformation temperatures as expressed by standard pyrometric cones of the high kaolin content mixtures;
6. Effect of the additions of kaolin to a mixture of 90 percent feldspar and 10 percent quartz.

In 1 and 2 it was desired to determine the relative rates of deformation of the various kaolin-feldspar mixtures compared with each other and also with the standard pyrometric cones.

The term "Deformation Eutectic" of 3 was coined by Prof. Staley.[2] Should there be two eutectics in the same series of mixtures, the mixture which gives the highest deformation temperature between the two might then be termed by us "A Deformation Compound," analogous to the melting point compounds.

Simonis (*Sprechsaal*, 1907, Vol. 2) gives a deformation temperature determination for Zettlitz kaolin feldspar mixtures and it was desirable in 5 to check this curve with our kaolin and feldspar.

Watts ("Some Data on the Deformation Points of Feldspar-Quartz Mixtures," Vol. 14, *T.A.C.S.*) found that there was apparently an eutectic with 90 percent feldspar and 10 percent quartz. As most commercial feldspars contain both quartz and kaolin impurities, it would be nearer actual working conditions

[2] "Melting Point and Deformation Eutectics," Vol. 8, *T. A. C. S.*

to have both present in this study, after the mixtures of feldspar with quartz and with kaolin had been investigated separately.

METHOD AND PROCEDURE

Preparation of the Feldspar. The purest microcline obtainable was used. It was thought best to start with as near theoretical conditions as possible and then as the study progressed, the various commercial feldspars and clays could be introduced. The chemical analysis of the feldspar and also of the theoretical microcline are as follows:

	Feldspar used	*Theoretical microcline*
	percent	*percent*
Moisture	0.17	.....
SiO_2	65.37	64.75
Al_2O_3	17.92	18.34
TiO_2	trace	.....
Fe_2O_3	0.02	.....
CaO	0.17	.....
MgO	trace	.....
K_2O	13.05	16.90
Na_2O	2.10	.....
	98.80	99.99
Specific gr.	2.57	2.56

The feldspar blocks, 2 in. by 4 in. in diameter were first cleaned by breaking off all discolored portions. These tainted parts were however very low in impurities and accordingly were used in the preliminary burn. The cleaned feldspar blocks were reduced by means of a geologist hammer on a large piece of pure quartz, to $\frac{3}{16}$ in. and smaller, sized particles. The final reduction was made by hand grinding in an agate mortar to pass a 200-mesh screen. Careful inspection was made at each step with the aid of a hand glass so that practically all discolored portions and minute muscovite particles were removed, leaving almost pure microcline.

Preparation of the Kaolin. As with the feldspar, the purest kaolin obtainable was used.

	Kaolin No. 83 *percent*	*Theoretical kaolin* *percent*
Moisture	12.22	13.90
SiO_2	46.67	46.30
Al_2O_3	39.07	39.80
Fe_2O_3	00.11	.....
TiO_2	00.02	.....
CaO	trace	.....
MgO	trace	.....
Na_2O	00.11	.....
K_2O	00.25	.....
	99.45	100.00

The crude unwashed clay was blunged in a small household churn, passed through a 200-mesh screen to remove all the larger quartz and mica particles and then sized in a Schultz elutriation apparatus, with a flow of water of 650 cc. per minute. References: "Experiments with Fine Grinding of Flint and Spar" by Junius F. Krehbiel, Vol. 6, *T.A.C.S.*; and Bulletin 53, U. S. Bureau of Mines, by A. S. Watts. This elutriation apparatus consists of a series of four jars with conical bases. Each has a thistle tube extending to the base through which the overflow from the jar above reaches the bottom. By means of an overflow reservoir and stopcock, a constant stream of water can be adjusted and maintained. The diameter of each jar thus determines the rate of upward flow of the water in that jar and likewise the size of particles which this rate of flow can carry up and over into the next jar. As each succeeding jar has a larger diameter, the size of particles retained in it will be smaller. See print of the apparatus, Figure 1.

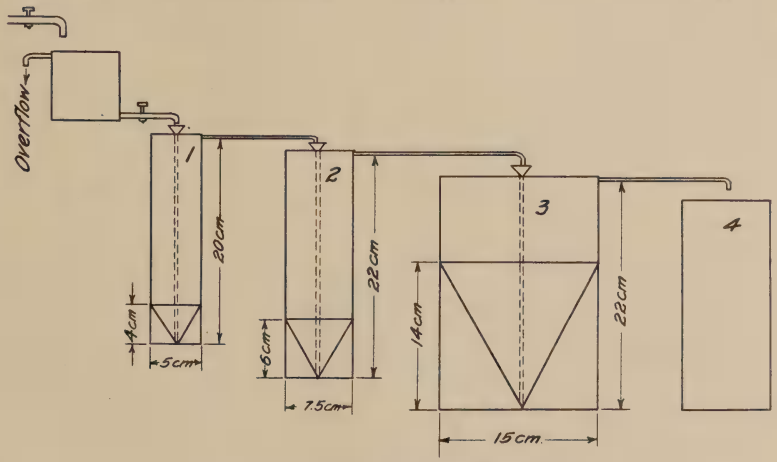
Four sizes of grain were separated, dried and their average size determined with a microscope.

Jar No. 1 = 0.0032 to 0.0040 inches
Jar No. 2 = 0.0024 to 0.0032 inches
Jar No. 3 = 0.0016 to 0.0024 inches
Jar No. 4 = 0.0008 to 0.0016 inches

Most of the clay grains were taken from Jar No. 3 and after the relative size of grain study, this size was used altogether for all the cones.

Preparation of the Cones. The feldspar and kaolin ingredients of the cone mixtures were weighed out on chemical laboratory balances to the nearest hundredths of a gram. The two were mixed dry by passing twice through a 150 in. mesh screen and enough dextrine added to permit its being formed by pressure in a die, into a standard sized cone, i.e., a three sided pyramid with sides $2\frac{7}{8}$ inches long and the faces $\frac{9}{16}$ inch, at the base and $\frac{1}{16}$ inch at the top. With an average weight of 5 gm. of material per cone, not more than 10 to 15 gram batches were prepared at one time. Each cone was stamped with its serial and clay content number and baked in a constant temperature oven at 109° C.

Trans. Am. Cer. Soc. Vol. XV Fig. 1. Wilson



Schultze Elutriation Apparatus
650 c.c. per minute

Arrangement of the Cones for Firing. When hardened, the cones were set in a fire clay plaque, at the same angle of slant and as close together as possible, with standard cones arranged to indicate heat conditions on all parts of the plaque. Because of the uneveness of the heat distribution and in order to interpret results, it was necessary to have several standard cones of the same number in different positions. The best arrangement of the cones was found to be as is shown in Figure 2.

The cones are placed in two slightly diverging lines, back to back, and so close together that they touch at the base. It was not found practicable to burn more than twelve (four to six being standards) at one time on account of the uneven heat distribution (Fig. 3). The plaque is placed in the portion of the muffle where the best uniform conditions have been found and slightly turned so that the two diverging lines of cones coincide with the

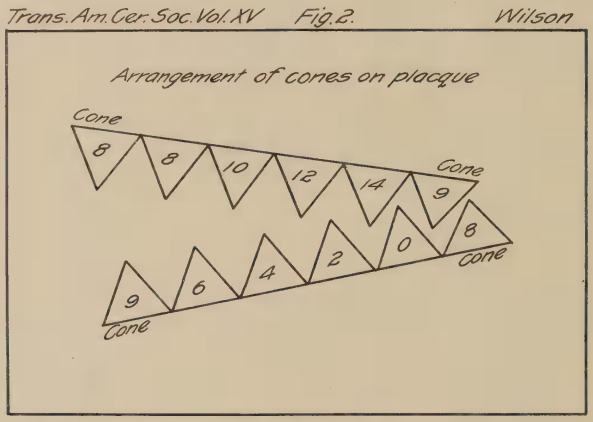
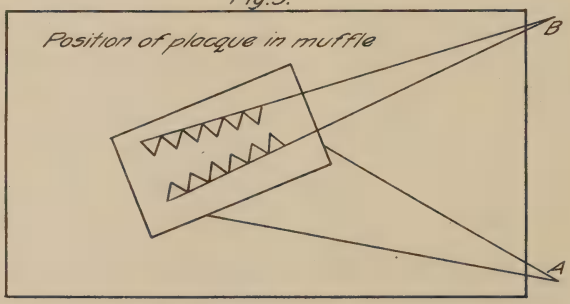


Fig. 3.



line of sight from peephole "B." However from that peephole you can not tell which cone is deforming, so peephole "A" is necessary from which you can count the cones and tell which is bending. From "B" the exact amount of bend can be ascertained. If the cones are placed so that they bend directly towards the peephole, they merely appear to shrink in length and it is difficult to determine just when they do start down.

It is better to make two short rows instead of one long one as a few inches may mean quite a difference in temperature. Also it is best to have the two rows fall in opposite directions; while this increases the area, it also prevents the one row from touching the other in deforming, especially when the order of starting is not known beforehand.

Firing. The best firing chamber was found to be a square flue lining, 6 in. by 6 in. by 24 in., closed tightly at both ends, save for the peepholes thus making a tight muffle. This was run into the chamber of a small coke fired test kiln at the Ohio State University. When necessary, two flue linings, one on top of the other with $2\frac{1}{4}$ in. between were used. In the upper, the higher temperature cones are placed, as that muffle keeps about two cones ahead of the lower. A cut of the kiln is shown in Figure 4.

From 24 to 27 hours were used in reaching cone 8; rapid firing maintained until cone 6 to 7 was reached and then several hours intervening until cone 8 should start.

DATA AND RESULTS

Effect of Size of Grain. To determine the effect of size of grain of the kaolin, a series was made up of 0.2, 5.0, 7.5, and 10 percent of each of the sizes Nos. 2, 3 and 4 of kaolin and fired as a preliminary burn. No difference could be distinguished between the three and so kaolin No. 3 was used throughout the rest of the determination.

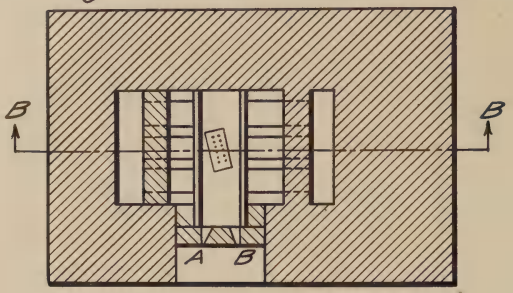
Deformation and Rate Study. Kaolin was added to feldspar in 1 percent intervals, from 0 to 16 percent. Beyond this the kaolin percents were 25, 30, 35, 40 and 45. The average of 9 burns is given in the accompanying chart.

The data for kaolin-feldspar mixtures is shown in a cone-deformation chart devised by Mr. Watts in Figure 5. This indicates that

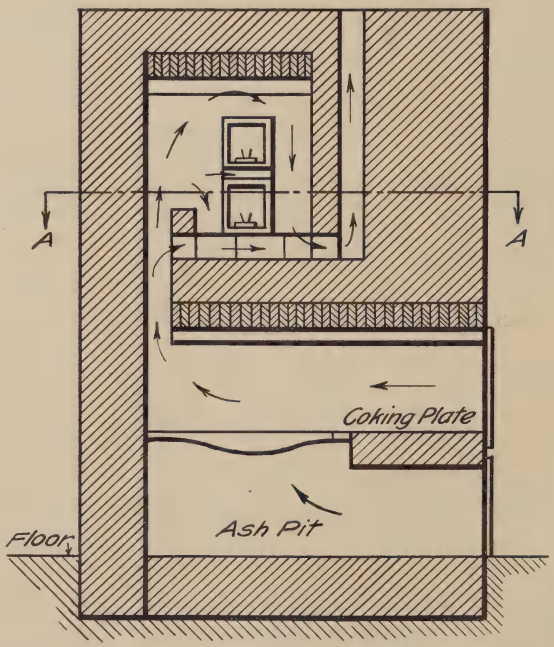
1. The pure feldspar deforms between cone 8 and cone 9, closer to the latter.

2. Around 2 and 3 percent kaolin, the start of deformation is late, the rate is fast, and the end is reached before that of pure feldspar.

Trans. Am. Cer. Soc. Vol. XV
Fig. 4. Wilson



Section on A-A



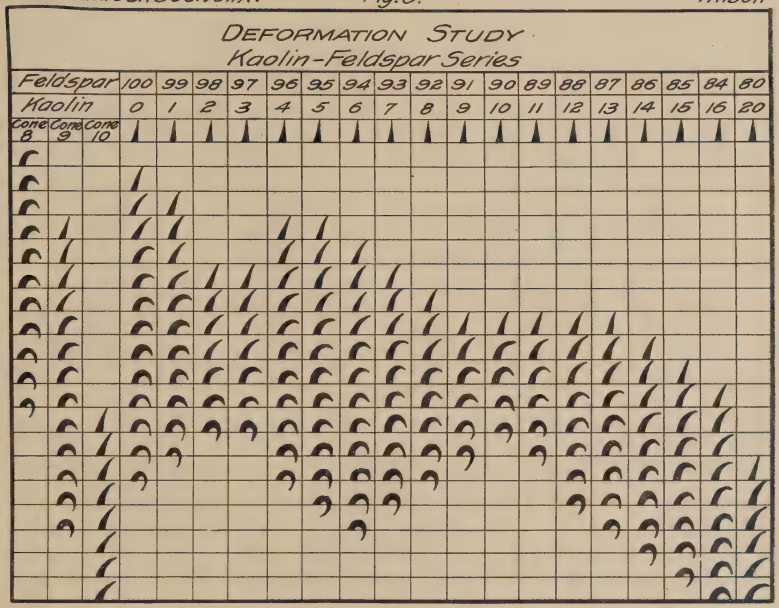
Section on B-B
Kiln No. 3.

3. At 5 and 6 percent the rate decreases until it is about that of the pure feldspar, but the start and finish of the deformation is behind that of the latter.

4. In the 9 to 11 percent region, there is another slow starting, a rapid rate and quick finish to deformation. The rate here is faster than any other.

5. Beyond 10 percent kaolin, the start and finish progresses towards higher temperatures with the increase of kaolin.

Trans. Am. Cer. Soc. Vol. XV Fig. 5. Wilson

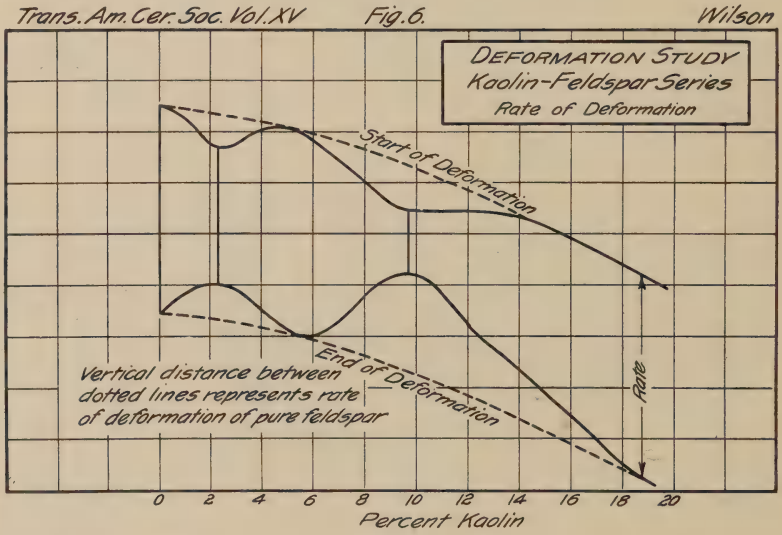


This chart is the result of the indications of the nine burns. Two feldspar cones in which the kaolin impurity varies only by one percent do not show much difference in their deformation. Hence regions, instead of definite percents, must be used in indicating eutectics.

Fig. 6 shows in a more general way the rate of deformation, the latter being designated by vertical distances between the two curves. The "normal" rate i.e., that of pure feldspar, is repre-

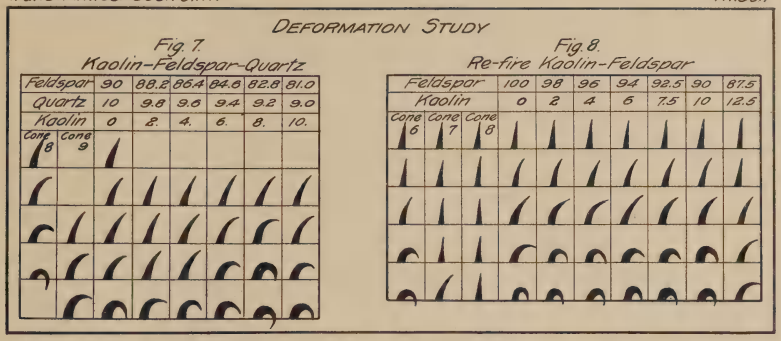
sented by the vertical distance between the two dotted lines dropping to the right as the kaolin content increases.

Conclusions. The results of these two charts show that, there are two indicated deformation eutectics, the lesser in the region of 2 to 3 percent kaolin and 98 to 97 percent feldspar, and the greater at 9 to 11 percent kaolin and 91 to 88 percent feldspar. Correspondingly 5 to 6 percent kaolin and 95 to 94 percent feldspar is a region which may be termed a deformation compound. Of course when we speak of regions, we mean that in the limits given, there is a definite percentage, at the maximum or minimum


Trans. Am. Cer. Soc. Vol. XV
Fig. 6.
Wilson
DEFORMATION STUDY
Kaolin-Feldspar Series
Rate of Deformation
Start of Deformation
End of Deformation
Rate
Vertical distance between dotted lines represents rate of deformation of pure feldspar
0 2 4 6 8 10 12 14 16 18 20
Percent Kaolin

point which should be termed the deformation compound, or eutectic, that but it has not been accurately determined.

Refiring. A final determination was made of this phase of the study by grinding up the deformed cones to pass 150 mesh, mixing with dextrine, reforming into cones and firing again. Cones containing 0, 2, 4, 6, 7.5, 10, 12.5 percent of kaolin were used. The results as given in Figure 7 check the above results, the deformation however taking place from 2 to 3 cones lower—close to cone 6. Pure feldspar started about the same time as the others but was slow in deforming. Cones of 2, 4, 7.5 and 10 percent kaolin



were practically the same and deformed more rapidly than pure feldspar. Cone of 6 percent kaolin was slightly behind the 2 and 10 percent and dropped more like 0 percent thus indicating the higher region of 4 to 6 percent.

KAOLIN-FELDSPAR-QUARTZ SERIES

Kaolin was added to a 1 to 9 mixture of quartz-feldspar in the percents 0, 2, 4, 6, 8, 10. The results of two burns are given in Figure 8. The deformation took place with cones 8 and 9, the same as with kaolin and feldspar alone. With 8 percent kaolin there was the most rapid deformation. Those of 10 percent and 0 percent kaolin came next with a lesser rate, leaving 2 to 4 percent as the "high" region, the slowest to deform.

Hence, in a general way, the feldspars with both quartz and kaolin impurities may deform with and before pure feldspar, especially when in the region of 8 to 10 percent kaolin, 9.2 to 9 quartz and 82.8 to 81.0 percent feldspar.

DEFORMATION OF HIGHER PERCENTS OF KAOLIN

Simonis (Sprechsaal, 1907, Vol. 2) gives the following table for the deformation of kaolin-feldspar mixtures:

NO.	ZETTLITZ KAOLIN	FELDSPAR	DEFORMATION POINT
	percent	*percent*	
67	15	85	Cone 9
74	30	70	Cone 14
80	45	55	Cone 26+
85	55	45	Cone 28
89	70	30	Cone 31+
92	85	15	Cone 33-34

As is shown by Figure 9 we partly checked this with our kaolin and feldspar, the slight variations probably due as much to furnace irregularities as to anything else. Standard sized cones were made of the different mixtures and tested with standard cones in a small gas fired muffle furnace. See Figure 10.

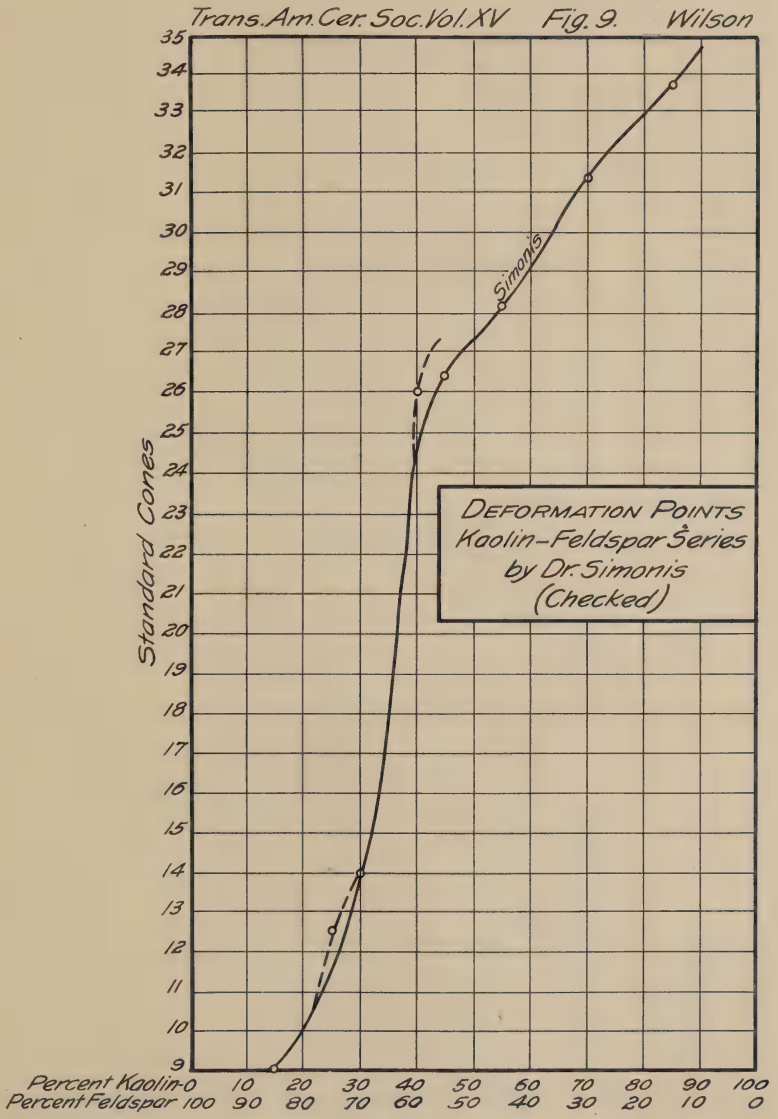
On the curve sheet, the dotted lines show where our results disagree with those of Simonis. Notice the rise in deformation of the 12 cones between the limits of 30 to 40 percent kaolin.

GENERAL CONCLUSIONS

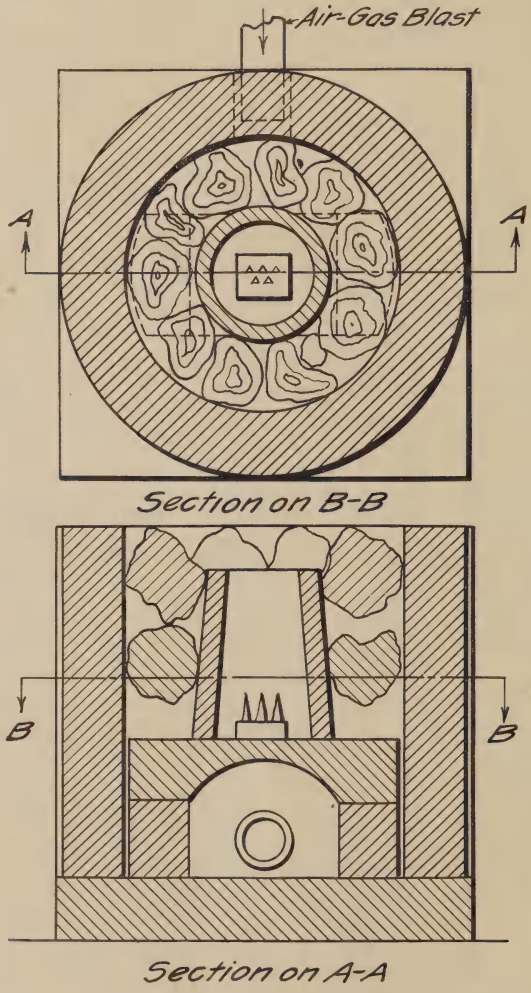
Deformation of a Cone. The deformation may be grouped into three stages: The first is that in which the cone vitrifies and shrinks in the upright condition. This may be accompanied by a slight bending in any direction which however, ceases before the true bending commences. This is the settling into a firm position and more compact mass.

The second period is the free bending. If the cone has been properly leaned the tip starts first, and as it bends, more of the part beneath is taken into the bend until when the top is on the level with the base, there is one continuous curve.

Much depends upon the rapidity of the burn. Cones show the result of time and temperature—heat work. If the temperature has been raised slowly, there is a better chance for the heat to penetrate into the cones gradually and for every bit of fluxing action of the alkalies to be completed, which could be completed at that temperature. Then there will be a selective deformation of the cones and greater differences can be discerned. When the temperature is raised rapidly, there comes a situation analogous to that of the supercooling of a liquid. Just as water can be cooled


Trans. Am. Cer. Soc. Vol. XV Fig. 9. Wilson
Standard Cones
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
Simonis
Deformation Points
Kaolin-Feldspar Series
by Dr. Simonis
(Checked)
Percent Kaolin 0 10 20 30 40 50 60 70 80 90 100
Percent Feldspar 100 90 80 70 60 50 40 30 20 10 0

Trans. Am. Cer. Soc. Vol. XV
Fig. 10. Wilson



High Temperature
Cone Muffle

below O°C. and remain in the liquid state, but upon the starting of crystallization the whole is suddenly changed into ice, so will the different cones hold back from deforming, and then all drop together as if charged with an excess of heat work. In this case, there is usually a straight fall, more like a stick of timber falling when stood up on end than an increasing curl. Because of the superabundance of heat work, the difference between the heat resisting force of the top and bottom of the cone is small when compared with the heat to be resisted.

Surface tension aids in the curling. The surface of the cone at the deformation period, is more or less of a fluid. Just as a drop of water assumes the spherical form when untouched, the sphere having the smallest surface of any shape, so will the fluid coating of a cone tend to draw the whole into a rounded mass, after the tip has decided the direction of bend. It has been noticed that the cones containing the higher percentages of kaolin, tend to curl more than those of no clay content. Raw clay in glazes causes greater shrinkage and in a cone mixture aids surface tension in getting the extremities of the cone together.

The third stage consists of the fusion of cone after the tip has gone below the level of the placque. As soon as it rests on something, the rest of the deformation is just a general slumping, the preliminary stage to the real melting.

The edges, formerly sharp, become indistinct and the whole rounds into a shapeless mass.

Importance of the Results. The rate of deformation, or "the range of temperature between the start and end of deformation" is very important, indicating the range of temperature within which this material will be valuable as a flux in pottery manufacture.

The method of putting a portion of the feldspar to be tested alone in the kiln and noting the result at the end of the burn will not always indicate the state of purity, for that feldspar can contain 10 percent quartz with 10 percent kaolin—20 percent impurity and still be deformed as much as the pure feldspar.

But what would be the difference? If a potter receives a feldspar which gives the desired fluidity at a certain cone, what difference does it make whether that spar contains a kaolin impurity

or not? A high grade kaolin costs more than a high grade feldspar. The objection to using a mixture for a pure feldspar, unknowingly, is that he never uses the feldspar alone, but always with kaolin and flint in his body or glaze mix. Therefore he may run his clay content abnormally high without knowing it, in the case of a mixed feldspar and produce a very refractory body. Also two apparently similar feldspars or mixtures, which alone produce similar results would give, upon the addition of clay, totally different conclusions. Ceramic mixtures are uncertain enough without adding to the uncertainty by starting with doubtful ingredients.

Hence to test feldspar for quartz impurities, add quartz; to test for kaolin impurity, add kaolin. Ten to fifteen percent kaolin added to a pure feldspar will not make appreciable difference in the final reading; but if added to a feldspar already containing 10 percent kaolin (the indicated eutectic) the difference in the final reading will be noticeable.

TESTS OF FLOOR TILE

BY F. B. O'CONNOR, ITHACA, N. Y.

The following tests on thin floor tile were performed mostly in the Economic Geology Laboratory of Cornell University by the writer under the supervision of Dr. Heinrich Ries[1] and they comprise, so far as the writer knows, the first detailed attempt to investigate the properties of this class of burned clay products. Those previously published are somewhat fragmentary. Emile Bourry, in his *Treatise on Ceramic Industries*, suggests two tests for floor tile, namely, the permeability (or absorption) test, and the test for resistance to wear. Both these have been included in this work along with such others as it was thought would bring out definite characteristics of the material.

In the present investigation three series of clay floor tiles were used. In addition a parallel series of tests were run on marble tile. The clay tile were supplied through the kindness of Mr. F. W. Walker, of the Beaver Falls Art Tile Company. They were all about $\frac{1}{2}$ inch thick, and square or rectangular. The marble tile were made to order of Vermont stone, $\frac{7}{16}$ inch thick, and 6 inches square.

The clay tile are known to the trade as vitrified, but they are not all non-absorbent. Instead of giving the name of the factories from which the tile were obtained, they will be referred to as Series A, B and C.

These tests were made (1) for the purpose of determining what the properties of standard makes of floor tile are, (2) to suggest if possible a series of required tests, and (3) to compare them with some other flooring materials.

The tests made were:

1. Impact on knife edges
2. Impact on plaster bed, knife edge blow
3. Impact on plaster bed, ball blow
4. Absorption
5. Frost resistance

[1] The balance of the tests were carried on in the Civil Engineering Laboratory of the same institution, and the writer desires to express herewith his obligations to Prof. A. P. Mills.

6. Abrasive resistance
7. Transverse strength

Although every effort was made to carry out the tests under uniform conditions, still there was more or less variation in the results. Some of this, at least, must have been due to the character of the samples tested. For this reason, a large number of tests were made, and only the most representative of the results taken.

The tests will now be taken up individually.

IMPACT TESTS

It will be seen from the list of tests given above that the impact test was carried out in three different ways, viz., (1) impact test on knife edges, the tile being struck with a knife edge from above; (2) impact test on plaster bed, the tile being held firmly on the latter while it received a blow with the knife edge from above; and (3) impact test with ball blow, the tile being held firmly on a plaster bed, while struck with a ball drop from above.

None of the three methods can be regarded as absolutely satisfactory, although the ball drop probably gave the best results for the reason that it imitated most closely the kind of blow or knock that the tile might be subject to when in use.

Impact Test on Knife Edges. The machine used in this test was of the ordinary drophammer type (see Plate I). The drop, which weighed three pounds, was of wood and was guided in its fall by a steel guide on either side which fitted into slots in the drop. The weight of the foundation (or anvil) of the machine was approximately 200 pounds which gives a ratio to weight of drop amply large to insure as accurate results as possible from a test of this sort. The guides were kept thoroughly oiled at all times, so it is thought a maximum percentage of the energy of the blow was transmitted to the test piece. Two hardened steel knife edges were placed parallel on the anvil, 4 inches center to center. The knife edge through which the blow was transmitted was carried on the drop so that it struck the specimen midway between the knife edges on the anvil and parallel to them. It is of course included in the weight of the drop previously given.

The impact test was made in two different ways. First, the hammer for the initial blow was raised only a small distance (about $\frac{1}{2}$ inch), the height of the drop being increased after that by increments of $\frac{1}{4}$ inch each blow until failure. Then a height slightly less than the average value of rupture was selected and a new set of specimens broken by a number of blows from this height.

Efforts to reduce the data for this latter part of the experiment proved a failure (except for the graphic solution to be taken up

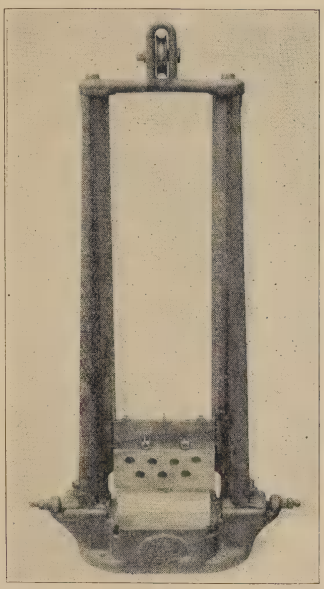


Plate I. Ball drop with plaster bed for making impact test on roofing tile

later) as did also the attempt to take into account the number of blows struck in the former part. Therefore the data is given as it was taken, with but one attempt at reduction, namely, by assuming that in the first part of the experiment the drop that broke the test piece was the first drop and the least height possible. For this case (the weight of the test piece being small compared to the weight of the hammer) Professor Church gives the formula (*Mechanics of Engineering*, p. 313)

$$Gh = \frac{1}{6}\frac{R^2k^2}{Ee^2}V \qquad (1)$$

where G = the weight of the hammer
h = the height of the drop
R = the modulus of rupture for impact
E = the modulus of elasticity
k = the geometric radius of gyration of a right section
e = the distance from the neutral axis to the extreme fiber in the right section
V = the volume of the test piece included between the two supporting knife edges

The volume V is

$$V = atl \qquad (2)$$

where a is the width and t the thickness of the specimen, and l the span. Substituting this value for V in (1), and rearranging we get

$$R = C\sqrt{h \div a} \qquad (3)$$

in which expression C is a constant for definite values of a and l, i.e.

$$C = \frac{e}{k}\sqrt{6EG \div tl} \qquad (4)$$

Using a value for E of 2,000,000[2] pounds per sq. in., and for G of 3 pounds we find (for values of a and l of $\frac{7}{16}$ in. and 4 in. respectively) C to be 7862.

Substituting this value for C in equation (3), we get the values of R for the different tile tested shown in Table I.

The results give the following average values of modulus of rupture for impact for the various colors and makes:

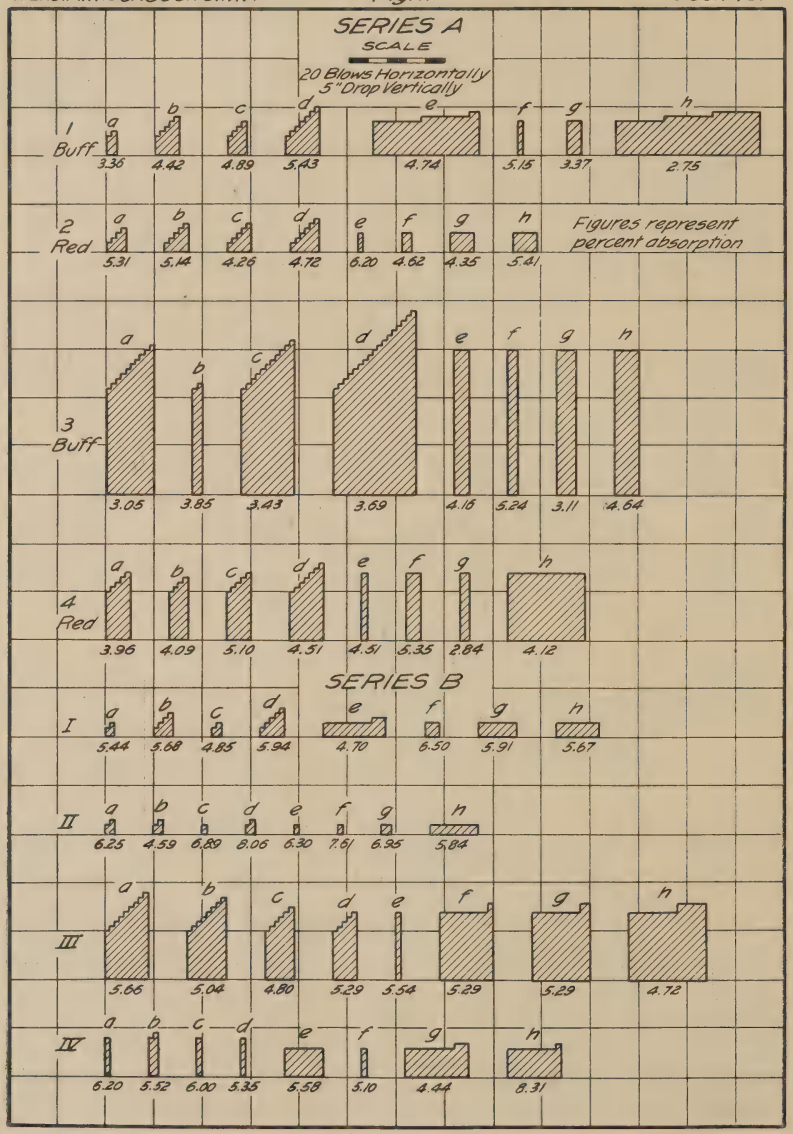
NAME	BUFF	RED	WHITE
	lbs. sq. in.	*lbs. sq. in.*	*lbs. sq. in.*
Series A	8170	6408	....
Series B	6679	5044	....
Series C	7091	5643	....
Vermont marble	....	....	7270

[2] The value E is at best only approximate, since it is not the same for all materials and might vary from one to three million.

TABLE I.—SERIES A

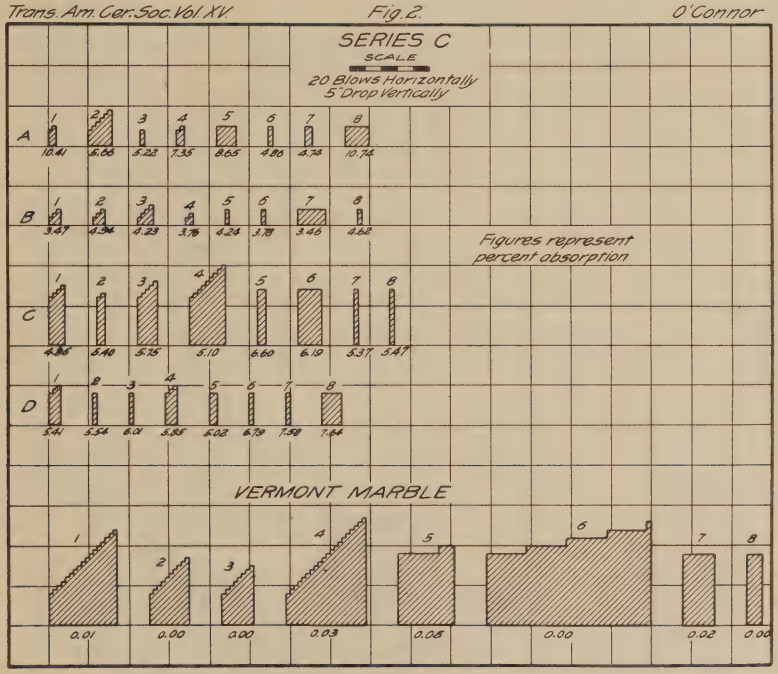
NO.	COLOR	h	a	R	NO.	COLOR	h	a	R
		ins.	*ins.*	*sq. ins.*			*ins.*	*ins.*	*sq. ins.*
(1)a	Buff	$1\frac{1}{4}$	2	6210	(3)a	Buff	$7\frac{3}{4}$	6	8980
b	Buff	2	2	7860	b	Buff	$5\frac{3}{4}$	6	7700
c	Buff	$1\frac{3}{4}$	2	7310	c	Buff	8	6	9050
d	Buff	$2\frac{1}{4}$	2	8340	d	Buff	$9\frac{1}{2}$	6	9910
(2)a	Red	$1\frac{1}{4}$	2	6210	(4)a	Red	$3\frac{1}{2}$	6	5980
b	Red	$1\frac{1}{2}$	2	6760	b	Red	$3\frac{1}{4}$	6	5820
c	Red	$1\frac{1}{2}$	2	6760	c	Red	$3\frac{1}{2}$	6	5980
d	Red	$1\frac{3}{4}$	2	7310	d	Red	4	6	6450
				SERIES B					
(I)a	Buff	$\frac{3}{4}$	2	4800	(III)a	Buff	$4\frac{1}{2}$	4	8190
b	Buff	$1\frac{1}{4}$	2	6210	b	Buff	$4\frac{1}{4}$	$4\frac{3}{16}$	7950
c	Buff	$\frac{3}{4}$	2	4800	c	Buff	$3\frac{3}{4}$	$4\frac{3}{16}$	7470
d	Buff	$1\frac{1}{2}$	2	6760	d	Buff	$3\frac{1}{2}$	$4\frac{3}{16}$	7150
(II)a	Red	$\frac{3}{4}$	2	4800	(IV)a	Red	$2\frac{1}{4}$	$4\frac{3}{16}$	5740
b	Red	$\frac{3}{4}$	2	4800	b	Red	2	$4\frac{3}{16}$	5430
c	Red	$\frac{1}{2}$	2	3930	c	Red	2	$4\frac{3}{16}$	5430
d	Red	$\frac{3}{4}$	2	4800	d	Red	2	$4\frac{3}{16}$	5430
				SERIES C					
(A)1	Buff	$1\frac{1}{4}$	2	6210	(C)1	Buff	$3\frac{3}{4}$	$4\frac{1}{4}$	7400
2	Buff	$2\frac{1}{4}$	2	8350	2	Buff	$3\frac{1}{4}$	$4\frac{1}{4}$	6840
3	Buff	1	2	5590	3	Buff	4	$4\frac{1}{4}$	7630
4	Buff	$1\frac{1}{4}$	2	6210	4	Buff	5	$4\frac{1}{4}$	8500
(B)1	Red	1	2	5590	(D)1	Red	$2\frac{1}{2}$	$4\frac{1}{4}$	6050
2	Red	1	2	5590	2	Red	2	$4\frac{1}{4}$	5420
3	Red	$1\frac{1}{4}$	2	6210	3	Red	2	$4\frac{1}{4}$	5420
4	Red	$\frac{3}{4}$	2	4800	4	Red	$2\frac{1}{2}$	$4\frac{1}{4}$	6050
				VERMONT MARBLE					
1	White	6	6	7860	3	White	$3\frac{3}{4}$	6	6200
2	White	$4\frac{1}{4}$	6	6630	4	White	$6\frac{3}{4}$	6	8330

An attempt has been made to represent the results of this test graphically (see Figs. 1 and 2). In these diagrams the height of the drop (ordinate) has been plotted against the number of blows (abscissae) so that the area (shaded) represents the relative work


Trans. Am. Cer. Soc. Vol. XV
Fig. 1.
O'Connor
SERIES A
SCALE
20 Blows Horizontally
5" Drop Vertically
1 Buff
a b c d e f g h
3.36 4.42 4.89 5.43 4.74 5.15 3.37 2.75
2 Red
a b c d e f g h
5.31 5.14 4.26 4.72 6.20 4.62 4.35 5.41
Figures represent percent absorption
3 Buff
a b c d e f g h
3.05 3.85 3.43 3.69 4.16 5.24 3.11 4.64
4 Red
a b c d e f g h
3.96 4.09 5.10 4.51 4.51 5.35 2.84 4.12
SERIES B
I
a b c d e f g h
5.44 5.68 4.85 5.94 4.70 6.50 5.91 5.67
II
a b c d e f g h
6.25 4.59 6.89 6.06 6.30 7.61 6.95 5.84
III
a b c d e f g h
5.66 5.04 4.80 5.29 5.54 5.29 5.29 4.72
IV
a b c d e f g h
6.20 5.52 6.00 5.35 5.58 5.10 4.44 8.31

done on the different test pieces. The figures under each diagram represent the percent absorption for that particular tile.

The main object of these diagrams was to show a relation, if possible, between the two methods of making the test, i.e., one method being that of varying the height of the drop, the other being that of making a number of blows with the same height



drop. As no care was taken to make the first drop from the same height for the different sizes of tile, these graphs form no basis of comparison between tile of the various sizes.

Details of Impact Tests. The following data give the details of the foregoing summarized tests. It should be noted that the break was not always perfectly straight as in Figure 3 but occasionally a V-shaped piece broke out as in Figure 4.

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Fig. 3.

Even Break

Fig. 4.

V-Shaped Break

SERIES A

(1) Tiles 2 in. by 6 in. by $\frac{7}{16}$ in., color buff
- a 1 in. by $1\frac{1}{4}$ in.; broke evenly
- b 1 in. by every $\frac{1}{4}$ in. to 2 in.; V-shaped break
- c 1 in. by every $\frac{1}{4}$ in. to $1\frac{3}{4}$ in.; V-shaped break
- d 1 in. by every $\frac{1}{4}$ in. to $2\frac{1}{2}$ in.; V-shaped break
- e 10 at $1\frac{3}{4}$ in., 10 at 2 in., 2 at $2\frac{1}{4}$ in.; broke evenly
- f 1 at $1\frac{3}{4}$ in.; V-shaped break
- g 3 at $1\frac{3}{4}$ in.; broke evenly
- h 10 at $1\frac{3}{4}$ in., 10 at 2 in., 10 at $2\frac{1}{2}$ in.; V-shaped break

(2) Tiles 2 in. by 6 in. by $\frac{7}{16}$ in., color red
- a $\frac{1}{2}$ in. by every $\frac{1}{4}$ in. to $1\frac{1}{4}$ in.; V-shaped break
- b $\frac{1}{2}$ in. by every $\frac{1}{4}$ in. to $1\frac{1}{2}$ in.; V-shaped break
- c $\frac{1}{2}$ in. by every $\frac{1}{4}$ in. to $1\frac{1}{2}$ in.; broke evenly
- d $\frac{1}{2}$ in. by every $\frac{1}{4}$ in. to $1\frac{3}{4}$ in.; V-shaped break
- e 1 at 1 in.; broke evenly
- f 2 at 1 in.; V-shaped break
- g 5 at 1 in.; broke evenly
- h 5 at 1 in.; V-shaped break

(3) Tiles 6 in. by 6 in. by $\frac{7}{16}$ in., color buff
- a $5\frac{1}{2}$ in. by every $\frac{1}{4}$ in. to $7\frac{3}{4}$ in.; V-shaped break
- b $5\frac{1}{2}$ in. to $5\frac{3}{4}$ in.; broke evenly
- c $5\frac{1}{2}$ in. by every $\frac{1}{4}$ in. to 8 in.; V-shaped break
- d $5\frac{1}{2}$ in. by every $\frac{1}{4}$ in. to $9\frac{1}{2}$ in.; splintered along break
- e 3 at $7\frac{1}{2}$ in.; broke evenly

f 2 at 7½ in.; broke evenly
g 4 at 7½ in.; V-shaped break
h 5 at 7½ in.; V-shaped break

(4) Tiles 6 in. by 6 in. by $\frac{7}{16}$ in., color red
a 2½ in. by every ¼ in. to 3½ in.; broke evenly
b 2½ in. by every ¼ in. to 3¼ in.; broke evenly
c 2½ in. by every ¼ in. to 3½ in.; broke evenly
d 2½ in. by every ¼ in. to 4 in.; broke evenly
e 1 at 3½ in.; broke evenly
f 3 at 3½ in.; broke evenly
g 2 at 3½ in.; broke evenly
h 16 at 3½ in.; broke evenly

SERIES D

(I) Tiles 2 in. by 6 in. by $\frac{7}{16}$ in., color buff
a ½ in. to ¾ in.; V-shaped break
b ½ in. by every ¼ in. to 1¼ in.; V-shaped break
c ½ in. to ¾ in.; broke evenly
d ½ in. by every ¼ in. to 1½ in.; V-shaped break
e 10 at ¾ in.; 3 at 1 in.; V-shaped break
f 3 at ¾ in.; broke evenly
g 8 at ¾ in.; broke evenly
h 9 at ¾ in.; V-shaped break

(II) Tiles 2 in. by 6 in. by $\frac{7}{16}$ in., color red
a ½ in. to ¾ in.; broke evenly
b ½ in. to ¾ in.; V-shaped break
c ½ in.; broke evenly
d ½ in. to ¾ in.; broke evenly
e 1 at ½ in.; broke evenly
f 1 at ½ in.; V-shaped break
g 2 at ½ in.; broke evenly
h 10 at ½ in.; V-shaped break

(III) Tiles 4$\frac{3}{16}$ in. by 4$\frac{3}{16}$ in. by $\frac{7}{16}$ in., color buff
a 2½ in. by every ¼ in. to 4½ in.; V-shaped break
b 2½ in. by every ¼ in. to 4¼ in.; broke evenly
c 2½ in. by every ¼ in. to 3¾ in.; V-shaped break
d 2½ in. by every ¼ in. to 3½ in.; broke evenly
e 1 at 3½ in.; broke evenly
f 10 at 3½ in.; 1 at 4 in.; broke evenly
g 10 at 3½ in.; 2 at 4 in.; V-shaped break
h 10 at 3½ in.; 6 at 4 in.; V-shaped break

(IV) Tiles $4\frac{3}{16}$ in. by $4\frac{3}{16}$ in. by $\frac{7}{16}$ in., color red

a 2 in.
b 2 in. to $2\frac{1}{4}$ in.; V-shaped break
c 2 in. broke evenly
d 2 in. V-shaped break
e 8 at $1\frac{1}{2}$ in.; broke evenly
f 1 at $1\frac{1}{2}$ in.; broke evenly
g 10 at $1\frac{1}{2}$ in.; 3 at $1\frac{3}{4}$ in.; V-shaped break
h 10 at $1\frac{1}{2}$ in.; 1 at $1\frac{3}{4}$ in. broke evenly

SERIES C

(A) Tiles 2 in. by $5\frac{7}{8}$ in. by $\frac{7}{16}$ in., color buff

1 1 in. to $1\frac{1}{4}$ in.; broke evenly
2 1 in. by every $\frac{1}{4}$ in. to $2\frac{1}{4}$ in.; broke evenly
3 1 in.; V-shaped break
4 1 in. to $1\frac{1}{4}$ in.; V-shaped break
5 5 at $1\frac{1}{4}$ in.; broke evenly
6 1 at $1\frac{1}{4}$ in.; broke evenly
7 2 at $1\frac{1}{4}$ in.; V-shaped break
8 6 at $1\frac{1}{4}$ in.; V-shaped break

(B) Tiles 2 in. by $5\frac{7}{8}$ in. by $\frac{7}{16}$ in., color red

1 $\frac{1}{2}$ in. by every $\frac{1}{4}$ in. to 1 in.; broke evenly
2 $\frac{1}{2}$ in. by every $\frac{1}{4}$ in. to 1 in.; broke evenly
3 $\frac{1}{2}$ in. by every $\frac{1}{4}$ in. to $1\frac{1}{4}$ in.; V-shaped break
4 $\frac{1}{2}$ in. to $\frac{3}{4}$ in.; broke evenly
5 1 at 1 in.; broke evenly
6 1 at 1 in.; broke evenly
7 7 at 1 in.; broke evenly
8 1 at 1 in.; broke evenly

(C) Tiles $4\frac{1}{4}$ in. by $4\frac{1}{4}$ in. by $\frac{7}{16}$ in., color buff

1 3 in. by every $\frac{1}{4}$ in. to $3\frac{3}{4}$ in.; V-shaped break
2 3 in. to $3\frac{1}{4}$ in.; V-shaped break
3 3 in. by every $\frac{1}{4}$ in. to 4 in.; V-shaped break
4 3 in. by every $\frac{1}{4}$ in. to 5 in.; even break
5 2 at $3\frac{1}{2}$ in.; V-shaped break
6 6 at $3\frac{1}{2}$ in.; even break
7 1 at $3\frac{1}{2}$ in.; V-shaped break
8 1 at $3\frac{1}{2}$ in.; even break

(D) Tiles $4\frac{1}{4}$ in. by $4\frac{1}{4}$ in. by $\frac{7}{16}$ in., color red

1 2 in. to $2\frac{1}{4}$ in. to $2\frac{1}{2}$ in.; V-shaped break
2 2 in.; even break
3 2 in.; even break
4 2 in. to $2\frac{1}{4}$ in. to $2\frac{1}{2}$ in.; V-shaped break
5 2 at 2 in.; V-shaped break

6 1 at 2 in.; V-shaped break
7 1 at 2 in.; V-shaped break
8 5 at 2 in.; even break

VERMONT MARBLE

1 2 in. by every $\frac{1}{4}$ in. to 6 in.; even break
2 2 in. by every $\frac{1}{4}$ in. to $4\frac{1}{4}$ in.; even break
3 2 in. by every $\frac{1}{4}$ in. to $3\frac{3}{4}$ in.; even break
4 2 in. by every $\frac{1}{4}$ in. to $6\frac{3}{4}$ in.; even break
5 10 at $4\frac{1}{2}$ in.; 4 at 5 in.; even break
6 10 at $4\frac{1}{2}$ in.; 10 at 5 in.; 10 at $5\frac{1}{2}$ in.; 10 at 6 in.; 1 at $6\frac{1}{2}$ in.; even break
7 8 at $4\frac{1}{2}$ in.; even break
8 4 at $4\frac{1}{2}$ in.; even break

Impact on Plaster Bed. This test seemed to suggest a better reproduction of the conditions which tile may be subjected to in use. Although there is no theory for determining a modulus from these tests, a work of drop per unit width of tile will give some idea of the strength of the tile and at the same time a basis for comparison of the different tile.

The machine used in this test was the same machine used in the previous test of impact on knife edges. The bed was formed by filling in between the knife edges with plaster of paris, and sand papering down until the plaster was smooth and formed a continuous plane surface between the knife edges.

No effort was made in these tests to break the piece by a number of blows from the same height. The tests were made by starting the hammer at a drop slightly less than that required for rupture, and increasing the height each time by increments of 1 inch until fracture occurred.

The method of reducing this data is by simply multiplying the drop at rupture by the weight of the hammer (3 lbs.) which gives the work done on the tile, and dividing this by the width of the tile, i.e.,

$$C' = \frac{G \times h}{w} = G\frac{h}{w} \tag{5}$$

where C' = the work in ins.-lbs. per inch of width, required to rupture the tile
G = the weight of the hammer = 3 lbs.
h = the height of drop at rupture in inches
w = the width of the specimen in inches

The values computed for C', by (5) for the various tile are given in Table II.

TABLE II.—SERIES A

NO.	COLOR	h	w	C'	NO.	COLOR	h	w	C'
		ins.	*ins.*	*lbs.*			*ins.*	*ins.*	*lbs.*
(1)i	Buff	4	2	6.0	(2)i	Red	2	2	3.0
j	Buff	3	2	4.5	j	Red	3	2	4.5
k	Buff	2	2	3.0	k	Red	2	2	3.0
l	Buff	3	2	4.5	l	Red	2	2	3.0
(3)i	Buff	10	6	5.0	(4)i	Red	8	6	4.0
j	Buff	13	6	6.5	j	Red	5	6	2.5
k	Buff	15	6	7.5	k	Red	8	6	4.0
l	Buff	15	6	7.5	l	Red	10	6	5.0
(5)a	White	8	3	8.0	(6)a	Light blue	10	3	10.0
b	White	7	3	7.0	b	Light blue	8	3	8.0
c	White	11	3	11.0	c	Light blue	6	3	6.0
d	White	7	3	7.0	d	Light blue	6	3	6.0
e	White	12	3	12.0	e	Light blue	10	3	10.0
(7)a	Pink	9	3	9.0	(8)a	Dark blue	7	3	7.0
b	Pink	10	3	10.0	b	Dark blue	7	3	7.0
c	Pink	7	3	7.0	c	Dark blue	9	3	9.0
d	Pink	6	3	6.0	d	Dark blue	7	3	7.0
(9)a	Dark green	6	3	6.0	(10)a	Med. green	12	3	12.0
b	Dark green	6	3	6.0	b	Med. green	8	3	8.0
c	Dark green	7	3	7.0	c	Med. green	7	3	7.0
d	Dark green	6	3	6.0	d	Med. green	9	3	9.0
(11)a	Light green	8	3	8.0	(12)a	Pearl gray	6	3	6.0
b	Light green	5	3	5.0	b	Pearl gray	6	3	6.0
c	Light green	7	3	7.0	c	Pearl gray	8	3	8.0
d	Light green	7	3	7.0	d	Pearl gray	9	3	9.0
(13)a	Flint gray	9	$4\frac{1}{4}$	6.2	(13)c	Flint gray	6	$4\frac{1}{4}$	4.2
b	Flint gray	13	$4\frac{1}{4}$	9.2	d	Flint gray	18	$4\frac{1}{4}$	12.7

SERIES B

(I)i	Buff	2	2	3.0	(II)i	Red	1	2	1.5
j	Buff	2	2	3.0	j	Red	1	2	1.5
k	Buff	2	2	3.0	k	Red	1	2	1.5
l	Buff	2	2	3.0	l	Red	1	2	1.5
(III)i	Buff	5	$4\frac{3}{16}$	3.6	(IV)i	Red	2	$4\frac{3}{16}$	1.4
j	Buff	5	$4\frac{3}{16}$	3.6	j	Red	2	$4\frac{3}{16}$	1.4
k	Buff	5	$4\frac{3}{16}$	3.6	k	Red	3	$4\frac{3}{16}$	2.2
l	Buff	6	$4\frac{3}{16}$	4.3	l	Red	4	$4\frac{3}{16}$	2.9

TABLE II.—Continued

SERIES C

NO.	COLOR	h	w	C'	NO.	COLOR	h	w	C'
(A) 9	Buff	1	2	1.5	(B) 9	Red	2	2	3.0
10	Buff	2	2	3.0	10	Red	1	2	1.5
11	Buff	1	2	1.5	11	Red	2	2	3.0
12	Buff	1	2	1.5	12	Red	1	2	1.5
(C) 9	Buff	4	$4\frac{1}{4}$	2.8	(D) 9	Red	3	$4\frac{1}{4}$	2.1
10	Buff	4	$4\frac{1}{4}$	2.8	10	Red	4	$4\frac{1}{4}$	2.8
11	Buff	5	$4\frac{1}{4}$	3.5	11	Red	5	$4\frac{1}{4}$	3.5
12	Buff	4	$4\frac{1}{4}$	2.8	12	Red	5	$4\frac{1}{4}$	3.5
					VERMONT MARBLE				
9	White	7	6	3.5	11	White	7	6	3.5
10	White	8	6	4.0	12	White	9	6	4.5

These values give the following average value of C' for different tile:

COLOR	MAKE			
	Series A	Series B	Series C	Vermont Marble
Buff	5.6	3.4	2.4	...
Red	3.6	1.7	2.6	...
White	9.0	...	...	3.9
Light blue	8.0	...	...	...
Pink	8.0	...	...	...
Dark blue	7.5	...	...	...
Dark green	6.2	...	...	...
Medium green	9.0	...	...	...
Light green	6.7	...	...	...
Pearl gray	7.2	...	...	...
Flint gray	8.1	...	...	...

The details of the impact test on plaster bed are as follows:

SERIES A

(1) Tiles 2 in. by 6 in. by $\frac{7}{16}$ in., color buff

i 4 in.; even break

j 3 in.; V-shaped break

k 2 in.; even break

l 3 in.; V-shaped break

Average = 3 in.

(2) Tiles 2 in. by 6 in. by $\frac{7}{16}$ in., color red
- i 2 in.; even break
- j 3 in.; even break
- k 2 in.; even break
- l 2 in.; even break

Average = $2\frac{1}{4}$ in.

(3) Tiles 6 in. by 6 in. by $\frac{7}{16}$ in., color buff
- i 10 in.; V-shaped break
- j 13 in.; even break
- k 15 in.; splintered
- l 15 in.; splintered

Average = $13\frac{1}{4}$ in.

(4) Tiles 6 in. by 6 in. by $\frac{7}{16}$ in., color red
- i 8 in.; even break
- j 5 in.; even break
- k 8 in.; V-shaped break
- l 10 in.; even break

Average = $7\frac{3}{4}$ in.

(5) Tiles 3 in. by 3 in. by $\frac{7}{16}$ in., color white
- a 8 in.; splintered
- b 7 in.; even break
- c 11 in.; splintered
- d 7 in.; splintered
- e 12 in.; splintered

Average = 9 in.

(6) Tiles 3 in. by 3 in. by $\frac{7}{16}$ in., color light blue
- a 10 in.; splintered
- b 8 in.; V-shaped break
- c 6 in.; splintered
- d 6 in.; V-shaped break
- e 10 in.; even break

Average = 8 in.

(7) $3\frac{7}{8}$ in. by 3 in. by $\frac{7}{16}$ in., color pink
- a 9 in.; splintered
- b 10 in.; even break
- c 7 in.; splintered
- d 6 in.; splintered

Average = 8 in.

(8) 3 in. by 3 in. by $\frac{7}{16}$ in., color dark blue
- a 7 in.; V-shaped break
- b 7 in.; splintered
- c 9 in.; splintered
- d 7 in.; splintered

Average = $7\frac{1}{2}$ in.

(9) 3 in. by 3 in. by $\frac{7}{16}$ in., color dark green
- a 6 in.; splintered
- b 6 in.; even break
- c 7 in.; splintered
- d 6 in.; even break

Average = $6\frac{1}{4}$ in.

(10) Tiles 3 in. by 3 in. by $\frac{7}{16}$ in., color medium green
- a 12 in.; splintered
- b 8 in.; splintered
- c 7 in.; splintered
- d 9 in.; splintered

Average = 9 in.

(11) Tiles 3 in. by 3 in. by $\frac{7}{16}$ in., color light green
- a 8 in.; splintered
- b 5 in.; even break
- c 7 in.; splintered
- d 7 in.; splintered

Average = $6\frac{3}{4}$ in.

(12) Tiles 3 in. by 3 in. by $\frac{7}{16}$ in., color pearl gray
- a 6 in.; splintered
- b 6 in.; splintered
- c 8 in.; splintered
- d 9 in.; splintered

Average = $7\frac{1}{4}$ in.

(13) Tiles $4\frac{1}{4}$ in. by $4\frac{1}{4}$ in. by $\frac{5}{8}$ in., color flint gray
- a 9 in.; splintered
- b 13 in.; splintered
- c 6 in.; even break
- d 18 in.; splintered

Average = $11\frac{1}{2}$ in.

SERIES B

(I) Tiles 2 in. by 6 in. by $\frac{7}{16}$ in., color buff

i 2 in.; even break
j 2 in.; even break
k 2 in.; even break
l 2 in.; even break
Average=2 in.

(II) Tiles 2 in. by 6 in. by $\frac{7}{16}$ in., color red

i 1 in.; even break
j 1 in.; even break
k 1 in.; even break
l 1 in.; even break
Average=1 in.

(III) Tiles $4\frac{3}{16}$ in. by $4\frac{3}{16}$ in. by $\frac{7}{16}$ in., color buff

i 5 in.; even break
j 5 in.; even break
k 5 in.; V-shaped break
l 6 in.; even break
Average=$5\frac{1}{4}$ in.

(IV) Tiles $4\frac{3}{16}$ in. by $4\frac{3}{16}$ in. by $\frac{7}{16}$ in., color red

i 2 in.; even break
j 2 in.; V-shaped break
k 3 in.; even break
l 4 in.; even break
Average=$2\frac{3}{4}$ in.

SERIES C

(A) Tiles 2 in. by $5\frac{7}{8}$ in. by $\frac{7}{16}$ in., color buff

9 1 in.; even break
10 2 in.; even break
11 1 in.; even break
12 1 in.; even break
Average=$1\frac{1}{4}$ in.

(B) Tiles 2 in. by $5\frac{7}{8}$ in. by $\frac{7}{16}$ in., color red

9 2 in.; even break
10 1 in.; even break
11 2 in.; even break
12 1 in.; even break
Average=$1\frac{1}{2}$ in.

(C) Tiles $4\frac{1}{4}$ in. by $4\frac{1}{4}$ in. by $\frac{7}{16}$ in., color buff

9 4 in.; even break
10 4 in.; V-shaped break
11 5 in.; V-shaped break
12 4 in.; V-shaped break
Average = $4\frac{1}{4}$ in.

(D) Tiles $4\frac{1}{4}$ in. by $4\frac{1}{4}$ in. by $\frac{7}{16}$ in., color red

9 3 in.; even break
10 4 in.; even break
11 5 in.; broke in quarters
12 5 in.; even break
Average = $4\frac{1}{4}$ in.

MARBLE

Vermont marble 6 in. by 6 in. by $\frac{7}{16}$ in., color white

9 7 in.; even break
10 8 in.; even break
11 7 in.; even break
12 9 in.; even break
Average = $7\frac{3}{4}$ in.

Impact Test with Ball Drop. After these tests were started, the criticism was made that in the Impact Test on Plaster Bed a ball and not a knife edge should be the medium through which the blow was transmitted to the test piece. The reasons given for this were two, namely; (1) the ball more nearly represented the condition met with in practice, it being thought that this was similar to the corner of a trunk or similar article striking the floor a sharp blow, and (2) the results would be more uniform in that the width of the tile would not enter. Whether or not the first reason carries any weight is a matter of conjecture. In regard to the second, the results show that the height of drop at fracture is not directly dependent on the width of the tile, but for comparison of results the tile must be of the same width. In other words, the width enters to a less and more vaguely defined extent in this test than in the test when the knife edge is used.

This test is an exact duplicate of the Impact Test on Plaster Bed previously described, with the exception that a hemisphere about 2 inches in diameter, was attached to the drop in place of the knife edge. The weight of the drop was kept at three pounds. In making the test the tile were put directly under the drop so

TABLE III.—SERIES A

(1) 2 in. by 6 in. by $\frac{7}{16}$ in. buff
(q) 5 in.
(r) 7 in.
(s) 3 in.
(t) 3 in.
(u) 4 in.
average = 4″.4

(2) 2 in. by 6 in. by $\frac{7}{16}$ in. red
(q) 3 in.
(r) 3 in.
(s) 3 in.
(t) 3 in.
(u) 3 in.
average = 3 ″.0

(3) 6 in. by 6 in. by $\frac{7}{16}$ in. buff
(q) 5 in.
(r) 7 in.
(s) 7 in.
(t) 4 in.
(u) 6 in.
average = 5″.8

(4) 6 in. by 6 in. by $\frac{7}{16}$ in. red
(q) 3 in.
(r) 3 in.
(s) 3 in.
(t) 3 in.
(u) 3 in.
average = 3″.0

(5) 3 in. by 3 in. by $\frac{7}{16}$ in. white
(q) 7 in.
(r) 7 in.
(s) 8 in.
(t) 7 in.
(u) 7 in.
average = 7″.2

(6) 3 in. by 3 in. by $\frac{7}{16}$ in. light blue
(q) 6 in.
(r) 7 in.
(s) 9 in.
(t) 10 in.
(u) 10 in.
average = 8″.4

(7) 3 in. by 3 in. by $\frac{7}{16}$ in. pink
(q) 5 in.
(r) 4 in.
(s) 5 in.
(t) 5 in.
(u) 5 in.
average = 4″.8

(8) 3 in. by 3 in. by $\frac{7}{16}$ in. dark blue
(q) 4 in.
(r) 4 in.
(s) 5 in.
(t) 6 in.
(u) 5 in.
average = 4″.8

(9) 3 in. by 3 in. by $\frac{7}{16}$ in. dark green
(q) 8 in.
(r) 9 in.
(s) 6 in.
(t) 5 in.
(u) 9 in.
average = 7″.4

(10) 3 in. by 3 in. by $\frac{7}{16}$ in. medi. green
(q) 9 in.
(r) 5 in.
(s) 5 in.
(t) 9 in.
(u) 8 in.
average = 7″.2

(11) 3 in. by 3 in. by $\frac{7}{16}$ in. light green
(q) 10 in.
(r) 11 in.
(s) 7 in.
(t) 9 in.
(u) 8 in.
average = 9″.0

(12) 3 in. by 3 in. by $\frac{7}{16}$ in. pearl gray
(q) 7 in.
(r) 8 in.
(s) 9 in.
(t) 9 in.
(u) 7 in.
average = 8″.0

TABLE III.—Continued

SERIES A

(13) $4\frac{1}{4}$ in. by $4\frac{1}{4}$ in. by $\frac{5}{8}$ in. flint gray
(q) 7 in.
(r) 11 in.
(s) 9 in.
(t) 13 in.
(u) 10 in.
average = 10″.0

SERIES B

(I) 2 in. by 6 in. by $\frac{7}{16}$ in. buff
(q) 2 in.
(r) 2 in.
(s) 2 in.
(t) 3 in.
(u) 2 in.
average = 2″.2

(II) 2 in. by 6 in. by $\frac{7}{16}$ in. red
(q) 2 in.
(r) 2 in.
(s) 2 in.
(t) 2 in.
(u) 2 in.
average = 2″.0

(III) $4\frac{3}{16}$ in. by $4\frac{3}{16}$ in. by $\frac{7}{16}$ in. buff
(q) 3 in.
(r) 4 in.
(s) 3 in.
(t) 3 in.
(u) 5 in.
average = 3″.6

(IV) $4\frac{3}{16}$ in. by $4\frac{3}{16}$ in. by $\frac{7}{16}$ in. red
(q) 3 in.
(r) 4 in.
(s) 4 in.
(t) 3 in.
(u) 4 in.
average = 3″.6

SERIES C

(A) 2 in. by $5\frac{7}{8}$ in. by $\frac{7}{16}$ in. buff
(q) 2 in.
(r) 2 in.
(s) 5 in.
(t) 2 in.
(u) 3 in.
average = 2″.8

(B) 2 in. by $5\frac{7}{8}$ in. by $\frac{7}{16}$ in. red
(q) 2 in.
(r) 2 in.
(s) 2 in.
(t) 2 in.
(u) 1 in.
average = 1″.8

(C) $4\frac{1}{4}$ in. by $4\frac{1}{4}$ in. by $\frac{7}{16}$ in. buff
(q) 5 in.
(r) 4 in.
(s) 5 in.
(t) 4 in.
(u) 5 in.
average = 4″.6

(D) $4\frac{1}{4}$ in. by $4\frac{1}{4}$ in. by $\frac{7}{16}$ in. red
(q) 3 in.
(r) 2 in.
(s) 3 in.
(t) 2 in.
(u) 3 in.
average = 2″.6

TABLE III.—Continued
VERMONT MARBLE

6 in. by 6 in. by $\frac{7}{16}$ in. white
(17) 6 in.
(18) 8 in.
(19) 7 in.
(20) 6 in.
(21) 6 in.
average = 6″.6

that the ball hit it in the center. There was no uniformity of break observed except that all the lines of fracture radiated from the center where the blow was struck, and in most cases the tile was crushed directly below the ball.

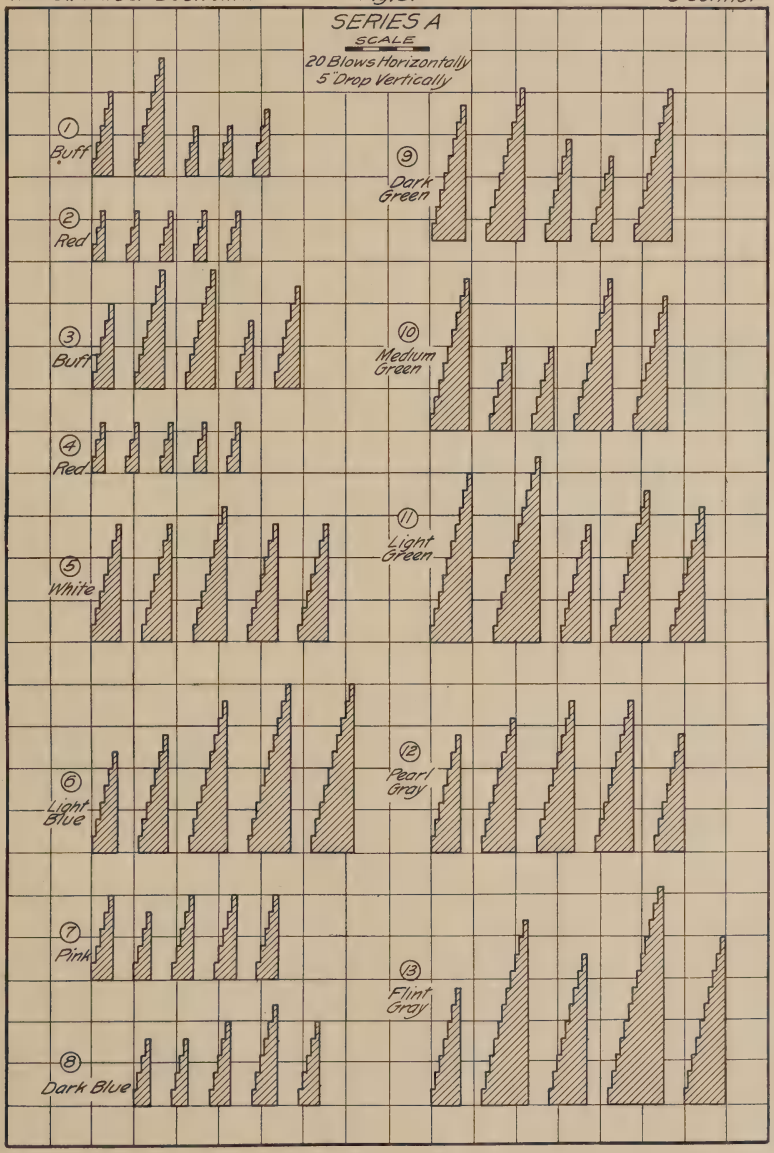
As no form of reduction suggested itself the results are stated, as the height of final drop. The initial drop in all cases was 1 in., and succeeding drops were increased by increments of 1 in.

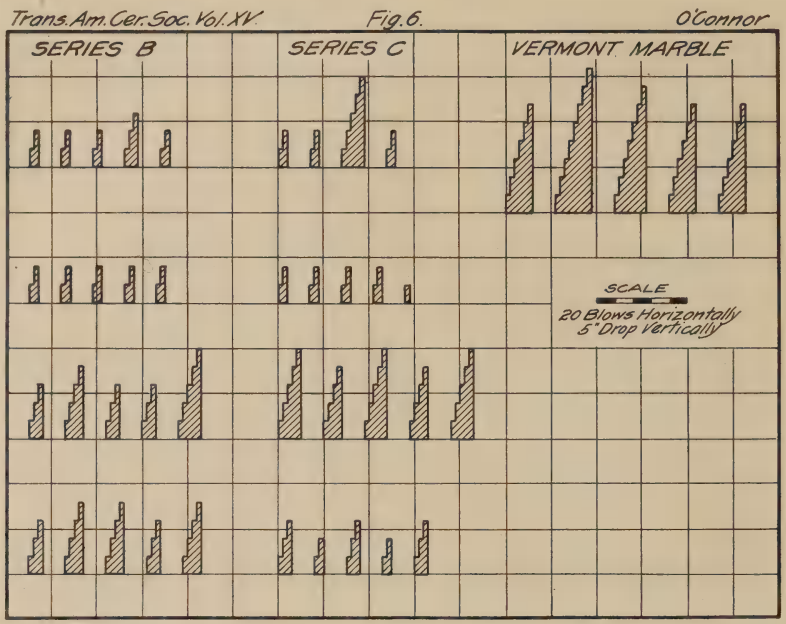
Graphs for this test have been drawn similar to those for the impact test on knife edges. See Figs. 5 and 6. They form a basis of comparison between tile of different size, which is not the case with those for the impact on knife edges, as the blows for this test were all started at the same height (1 inch) and increased uniformly 1 inch at a time.

Comments on Impact Tests. It is realized of course that the impact tests are not absolutely accurate. In fact they are not, unless so carried out that the energy remaining in the hammer after breaking the test piece can be measured, so that by the difference in initial and final conditions of the hammer, the work absorbed by the test piece can be found. This was not possible in these tests. The next best plan, is the one adopted, viz., of starting with light blows and increasing the height of the drop of the hammer until the tile breaks.

Another cause of variable results may be the character of the supporting surface. It is difficult to get the pieces evenly supported on the knife edges, for while these may be straight, the tile itself may be very slightly warped. Every tile was carefully examined before it was tested, but still minor irregularities might escape notice. Uneven support would of course mean variable results, due to secondary stresses being set up in the tile. However, the writer believes that the supports were even enough to make the effect of these secondary stresses practically negligible.

Trans. Am. Cer. Soc. Vol. XV Fig. 5. O'Connor





ABSORPTION TEST

In this test the tile used in the Impact on Knife Edges Test were weighed and placed in water for approximately 48 hours with all but one surface covered. At the end of this time, they were taken out, the water wiped off the faces, and weighed again. The percent absorption was computed from the following formula:

$$A = \frac{W' - W}{W} \times 100 \qquad (6)$$

where Z = the percent absorption
W = the dry weight
W' = the wet weight

The results for this experiment are shown in Table IV.

Table V gives the average, maximum, and minimum values of absorption for the various tile tested.

TABLE IV.—SERIES A

NO.	COLOR	*A*	NO.	COLOR	*A*
		percent			*percent*
(1)a	Buff	3.36	(2)a	Red	5.31
b	Buff	4.42	b	Red	5.14
c	Buff	4.89	c	Red	4.26
d	Buff	5.43	d	Red	4.72
e	Buff	4.74	e	Red	6.20
f	Buff	5.15	f	Red	4.62
g	Buff	3.37	g	Red	4.35
h	Buff	2.75	h	Red	5.41
(3)a	Buff	3.05	(4)a	Red	3.96
b	Buff	3.85	b	Red	4.09
c	Buff	3.43	c	Red	5.10
d	Buff	3.69	d	Red	4.51
e	Buff	4.16	e	Red	4.51
f	Buff	5.24	f	Red	5.35
g	Buff	3.11	g	Red	2.84
h	Buff	4.64	h	Red	4.12
(5)a	White	0.06	(6)a	Light blue	0.01
b	White	0.01	b	Light blue	0.02
c	White	0.01	c	Light blue	0.00
d	White	0.07	d	Light blue	0.00
e	White	0.00	e	Light blue	0.03
(7)a	Pink	0.84	(8)a	Dark blue	0.04
b	Pink	0.48	b	Dark blue	0.02
c	Pink	0.44	c	Dark blue	0.04
d	Pink	0.72	d	Dark blue	0.05
(9)a	Dark green	0.00	(10)a	Medium green	0.00
b	Dark green	0.00	b	Medium green	0.00
c	Dark green	0.00	c	Medium green	0.00
d	Dark green	0.02	d	Medium green	0.00
(11)a	Light green	0.03	(12)a	Pearl gray	0.00
b	Light green	0.01	b	Pearl gray	0.04
c	Light green	0.00	c	Pearl gray	0.00
d	Light green	0.00	d	Pearl gray	0.04
(13)a	Flint gray	0.02	(13)c	Flint gray	0.00
b	Flint gray	0.05	d	Flint gray	0.01

TABLE IV.—Continued

SERIES B

NO.	COLOR	*A*	NO.	COLOR	*A*
		percent			*percent*
(I)a	Buff	5.44	(II)a	Red	6.25
b	Buff	5.68	b	Red	4.59
c	Buff	4.85	c	Red	6.89
d	Buff	5.94	d	Red	8.06
e	Buff	4.70	e	Red	6.30
f	Buff	6.50	f	Red	7.61
g	Buff	5.91	g	Red	6.95
h	Buff	5.67	h	Red	5.84
(III)a	Buff	5.66	(IV)a	Red	6.20
b	Buff	5.04	b	Red	5.52
c	Buff	4.80	c	Red	6.00
d	Buff	5.29	d	Red	5.35
e	Buff	5.54	e	Red	5.58
f	Red	5.29	f	Red	5.10
g	Buff	5.29	g	Red	4.44
h	Buff	4.72	h	Red	8.31
		SERIES C			
(A)1	Buff	10.41	(B)1	Red	3.47
2	Buff	5.66	2	Red	4.94
3	Buff	5.22	3	Red	4.23
4	Buff	7.35	4	Red	3.76
5	Buff	8.65	5	Red	4.24
6	Buff	4.86	6	Red	3.78
7	Buff	4.74	7	Red	3.46
8	Buff	10.74	8	Red	4.62
(C)1	Buff	4.95	(D)1	Red	5.41
2	Buff	5.40	2	Red	5.54
3	Buff	5.75	3	Red	6.01
4	Buff	5.10	4	Red	5.85
5	Buff	6.60	5	Red	5.02
6	Buff	6.19	6	Red	6.79
7	Buff	5.37	7	Red	7.58
8	Buff	5.47	8	Red	7.64
		VERMONT MARBLE			
1	White	0.01	5	White	0.05
2	White	0.00	6	White	0.00
3	White	0.00	7	White	0.02
4	White	0.03	8	White	0.00

TABLE V—SERIES A

COLOR	AVERAGE	MAXIMUM	MINIMUM
Buff	4.11	5.43	2.75
Red	4.65	6.20	2.84
White	0.03	0.07	0.00
Light blue	0.01	0.03	0.00
Pink	0.62	0.84	0.44
Dark blue	0.04	0.05	0.02
Dark green	0.00	0.02	0.00
Medium green	0.00	0.00	0.00
Light green	0.02	0.03	0.00
Pearl gray	0.02	0.04	0.00
Flint gray	0.02	0.05	0.00
SERIES B			
Buff	5.39	6.50	4.70
Red	6.18	8.31	4.44
SERIES C			
Buff	6.40	10.76	4.74
Red	5.14	7.64	3.46
VERMONT MARBLES			
White	0.01	0.05	0.00

FREEZING TEST

In this test the tile were first immersed in water until they were thoroughly soaked. Then they were submitted to a temperature below freezing. After remaining in this freezing temperature twenty-four hours, they were taken out and immersed in water at room temperature for another twenty-four hours. This process was repeated twenty times, the tile being examined for cracks or breaks after each freezing. At the end of the test all the tiles were broken to see to what extent the adhesion of the particles had been broken down by the freezing.

The only effects noted previous to the twentieth freezing were as follows:

After 3rd freezing.....	(3a)	Buff tile, Series A, cracked.
	(3f)	Buff tile, Series A, corner broken off.
After 8th freezing.....	(1a)	Buff tile, Series A, corner broken off.
	(3h)	Buff tile, Series A, corner broken off.
After 9th freezing.....	(3d)	Buff tile, Series A, cracked.
	(3g)	Buff tile, Series A, cracked.
After 16th freezing.....	(1h)	Buff tile, Series A, cracked.

All the other cracks that are reported under the final examination occurred during the last or twentieth freezing.

The report of the final examination is shown in Table VI.

TABLE VI—SERIES A

	Buff		*Red*
(1)	a sound	(2)	a sound
	b sound		b sound
	c sound		c sound
	d sound		d sound
	e sound		e sound
	f sound		f sound
	g sound		g sound
	h cracked. Broke up easily. Brittle.		h sound

	Buff		*Red*
(3)	a surface crack	(4)	a sound
	b sound		b cracked. Broke with difficulty
	c sound		c sound
	d cracked. Broke up fairly easily		d sound
	e sound		e sound
	f cracked. Broke easily		f sound
	g cracked. Broke with difficulty		g sound
	h cracked. Broke with difficulty		h sound

SERIES B

	Buff		*Red*
(I)	a sound	(II)	a sound
	b sound		b sound
	c sound		c sound
	d sound		d sound
	e sound		e sound
	f sound		f sound
	g sound		g sound
	h sound		h sound

TABLE VI.—Continued

SERIES B

	Buff		*Red*
(III)	a sound	(IV)	a sound
	b sound		b sound
	c sound		c sound
	d sound		d sound
	e sound		e sound
	f cracked. Broke with difficulty		f sound
	g sound		g sound
	h sound		h sound

SERIES C

	Buff		*Red*
(A)	1 sound	(B)	1 sound
	2 sound		2 sound
	3 sound		3 sound
	4 sound		4 sound
	5 cracked. Broke with difficulty		5 sound
	6 sound		6 sound
	7 sound		7 sound
	8 sound		8 cracked. Broke with difficulty

	Buff		*Red*
(C)	1 sound	(D)	1 sound
	2 sound		2 sound
	3 sound		3 sound
	4 sound		4 sound
	5 sound		5 sound
	6 sound		6 sound
	7 sound		7 sound
	8 sound		8 sound

VERMONT MARBLE

1 sound
2 sound
3 sound
4 sound
5 sound
6 sound
7 sound
8 sound

It will be noted that not one of the tile broke from the effect of the freezing, that is, when the final examination was made, though several were cracked, none were found broken.

ABRASION TEST

These tests were made on the Riehlé Abrasion Testing Machine in the Laboratory of the College of Civil Engineering, Cornell University. This machine is shown in Plate II. It consists of a revolving table, about four feet in diameter, of machinery cast iron on which the test piece was held by a pair of jaws that were moved back and forth at a slow rate along a diameter of the table.

The table was revolved at a speed of approximately 1500 revolutions per hour. The abrasion material was a pure silica sand obtained by crushing quartz rock. This sand was furnished by the Silica Products Company, of Lancaster, Pa. Only that portion of it which passed through a number 20 and stopped on a number 30 sieve was used in this test. The tile was placed on the revolving plate of the machine and held there for 1500 revolutions, several different pressures being tried as shown in the tables given below. Two liters of dry sand were fed on to the table at a uniform rate.

At the end of the test, the thickness was measured at eight different points, and the mean of these taken. The original thickness was $\frac{7}{16}$ inch, and so the loss in thickness was expressed in percentage terms of the original thickness. The reason the results are not expressed in weight loss is because some of the tile, showed a tendency to chip on the edges, and hence the loss by weight would not mean much. This chipping might be ascribed to faults in the design of the machine, were it not for the fact that the chipping was confined to the buff tile. Both the red and buff tile showed a tendency to groove somewhat on the abraded surface. The results follow:

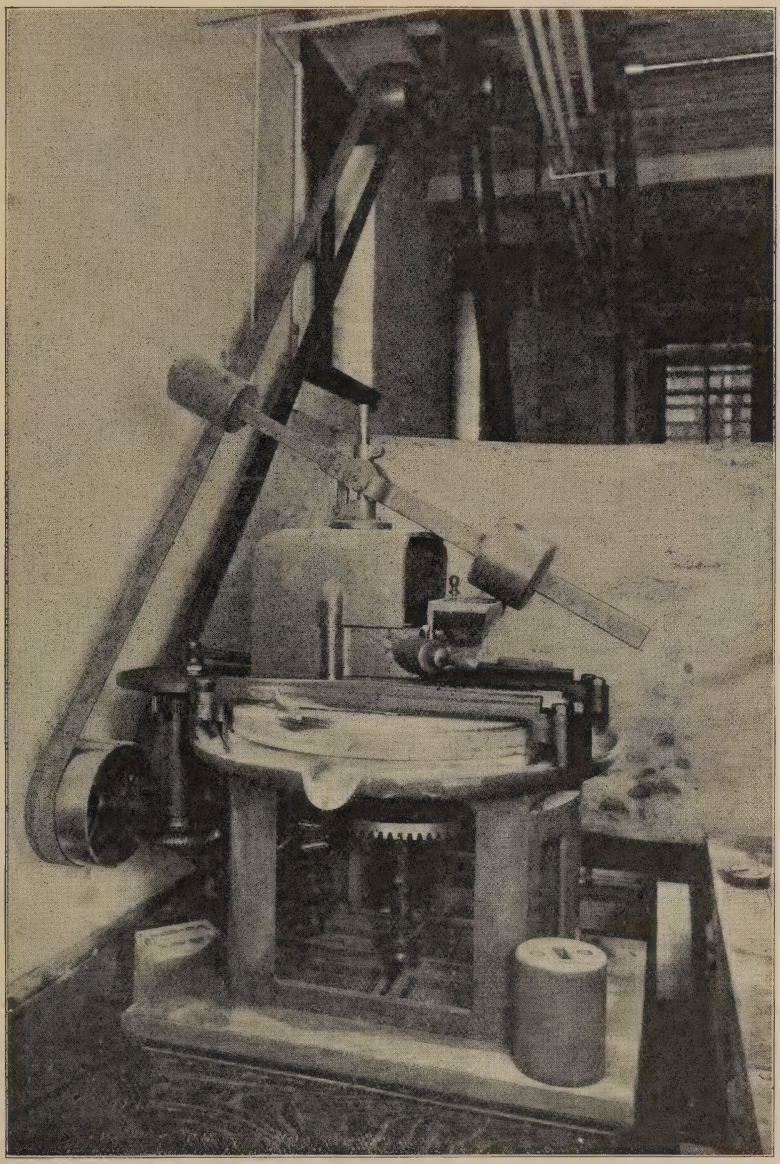


Plate II. Riehle abrasion testing machine

Weight applied, 4.25 pounds per square inch, tile 2 by 6 inches.

SERIES	COLOR	PERCENT LOSS IN THICKNESS
A	Buff	12.21
A	Red	21.24
B	Buff	21.57
B	Red	35.55
C	Buff	29.80
C	Red	18.43

Weight applied, 4 pounds per square inch, tile $4\frac{1}{4}$ by $4\frac{1}{4}$ inches.

B	Buff	14.32
	Red	10.16
C	Buff	21.14
	Red	6.89

Weight applied, 3.75 pounds per square inch, tile 6 by 6 inches.

A	Buff	3.78
	Red	12.00
Vermont marble		57.30

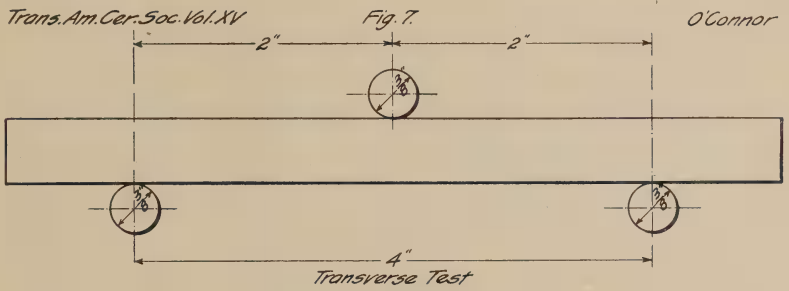
Lack of time prevented me from carrying out the abrasion tests in much detail, and yet the above figures are not without interest. As might be expected, the loss increases, with the pressure. In both Series A and B, the buff tile show higher abrasive resistance than the red, but in series C the reverse appears to be true. However further tests must be made to definitely settle this point. The high abrasive loss of the Vermont marble floor tile was not unexpected.

TRANSVERSE TEST

This test was performed by resting the tile on two hardened steel rollers, $\frac{3}{8}$ inch in diameter, and transmitting the load through another roller, $\frac{3}{8}$ inch in diameter, placed parallel to the supporting ones and in the middle of the span as shown in Figure 7. This whole apparatus was placed in an ordinary 10,000 pound Olsen crushing machine in the laboratory of the College of Civil Engineering, Cornell University, and the load applied and measured in this way. The rollers were held exactly in place by wooden

templates, and the load was applied gradually and continuously from start to failure.

It is well known that with short spans the piece subjected to a transverse load is quite as likely to fail by shear (or the combination of shear and tension) as by tension and compression alone. For this reason care was taken in every instance to examine the break. In all cases the break was vertical and occurred directly under the load, where the shear passes through zero. Hence it is thought that the moduli of rupture obtained from these tests are reliable. If shear had helped cause the failure, the break would have been diagonal and at some point between the support and the load.



The modulus of rupture was computed from the regular formula:

$$f = \frac{3Pl}{2bh^2} \tag{7}$$

where f = the modulus of rupture in lbs. per sq. in.
p = the breaking force in pounds.
l = the span in inches.
b = the width of section in inches.
h = the depth of section in inches.

For all the buff and red tile tested, the span was 4 inches and the depth of the section $\frac{7}{16}$ inches, so that for this case equation (7) reduces to:

$$f = \frac{3l}{2h^2} \cdot \frac{P}{b} \frac{3 \times 4}{2 \times (\frac{7}{16})} = \frac{P}{b} = 31.4 \frac{P}{b} \tag{8}$$

For all the rest of the tile, except the flint gray of Series A, the

span was $2\frac{1}{2}$ inches, the width was 3 inches, and the depth was $\frac{7}{16}$ inches, so that for this case equation (7) reduces to

$$f = \frac{3 \times 2\frac{1}{2}}{2 \times (\frac{7}{16})^2 \times 3} P = 6.53\,P \qquad (9)$$

The values of f given in Table VII have been computed from the results obtained, using equation (8) for the buff and red tile, equation (7) for the flint gray tile and equation (9) for all the other tile. The Vermont Marble was figured from equation (8).

TABLE VII—SERIES A

NO.	COLOR	P	b	f	NO.	COLOR	P	b	f
		lbs.	*ins.*	*lbs. per sq. in.*			*lbs.*	*ins.*	*lbs. per sq. in.*
(1)m	Buff	294.7	2	4620	(2)m	Red	285.6	2	4470
n	Buff	400.7	2	6290	n	Red	272.2	2	4270
o	Buff	519.2	2	8140	o	Red	238.9	2	2744
p	Buff	515.2	2	8080	p	Red	252.2	2	3960
(3)m	Buff	918.9	6	4800	(4)m	Red	481.7	6	2520
n	Buff	705.3	6	3690	n	Red	537.2	6	2805
o	Buff	1000.6	6	5250	o	Red	643.7	6	3360
p	Buff	789.4	6	4120	p	Red	376.9	6	1967
(5)f	White	1253.3		8180	(6)f	Light blue	788.3		5148
g	White	1179.1		7690	g	Light blue	669.5		4366
h	White	1126.2		7350	h	Light blue	922.6		6022
i	White	1180.1		7700	i	Light blue	1036.7		6770
(7)f	Pink	699.4		4560	(8)e	Dark blue	971.1		6340
g	Pink	714.7		4660	f	Dark blue	1023.2		6680
h	Pink	742.5		4850	g	Dark blue	772.0		5040
i	Pink	535.3		3500	h	Dark blue	1166.0		7600
(9)e	Dark green	906.6		5910	(10)e	Med. green	1132.1		7390
f	Dark green	924.4		6030	f	Med. green	1214.7		7940
g	Dark green	545.8		3560	g	Med. green	1065.0		6950
h	Dark green	828.0		5400	h	Med. green	1134.0		7410
(11)e	Light green	721.8		4710	(12)e	Pearl gray	1029.1		6720
f	Light green	954.9		6240	f	Pearl gray	639.7		4180
g	Light green	1100.0		71 0	g	Pearl gray	519.8		3390
h	Light green	1248.1		8150	h	Pearl gray	775.1		5060
(13)e	Flint gray	1017.2		3680	(13)e	Flint gray	1442.7		5220
f	Flint gray	1170.7		4240	f	Flint gray	1367.0		4950

TABLE VII.—Continued
SERIES B

NO.	COLOR	P	b	f	NO.	COLOR	P	b	f
		lbs.	*ins.*	*lbs. per sq. in.*			*lbs.*	*ins.*	*lbs. per sq. in.*
(I)m	Buff	315.5	2	4885	(II)m	Red	210.8	2	2520
n	Buff	204.5	2	3205	n	Red	197.1	2	2805
o	Buff	285.7	2	4475	o	Red	222.1	2	3360
p	Buff	249.0	2	3900	p	Red	191.0	2	1967
(III)m	Buff	568.9	$4\frac{3}{16}$	4255	(IV)m	Red	243.5	$4\frac{3}{16}$	4470
n	Buff	669.2	$4\frac{3}{16}$	5010	n	Red	255.2	$4\frac{3}{16}$	4270
o	Buff	455.3	$4\frac{3}{16}$	3415	o	Red	388.8	$4\frac{3}{16}$	2744
p	Buff	530.8	$4\frac{3}{16}$	3980	p	Red	318.0	$4\frac{3}{16}$	3960
SERIES C									
(A)13	Buff	231.8	2	3635	(B)13	Red	249.0	2	3304
14	Buff	188.8	2	2956	14	Red	200.2	2	3088
15	Buff	245.7	2	3846	15	Red	189.8	2	3482
16	Buff	218.7	2	3432	16	Red	237.0	2	2994
(C)13	Buff	436.8	$4\frac{1}{4}$	3223	(D)13	Red	434.7	$4\frac{1}{4}$	1821
14	Buff	419.2	$4\frac{1}{4}$	3086	14	Red	443.3	$4\frac{1}{4}$	1910
15	Buff	589.3	$4\frac{1}{4}$	4345	15	Red	263.2	$4\frac{1}{4}$	2912
16	Buff	536.0	$4\frac{1}{4}$	3959	16	Red	573.9	$4\frac{1}{4}$	2308
VERMONT MARBLE									
1	White	367.8	6	1921	3	White	452.5	6	2365
2	White	528.0	6	2758	4	White	626.0	6	3275

The average value of the modulus of rupture for the various tile are:

COLOR	SERIES A	SERIES B	SERIES C	VERMONT MARBLE
Buff	5624	4141	3560	....
Red	3262	3262	2725	....
White	7730	....	....	2580
Light blue	5576	....	....	....
Pink	4392	....	....	....
Dark blue	6415	....	....	....
Dark green	5225	....	....	....
Medium green	7422	....	....	....
Light green	4572	....	....	....
Pearl gray	4887	....	....	....
Flint gray	4522	....	....	....

DISCUSSION OF RESULTS

The Transverse Test as it stands is of little value in determining the quality of tile for actual use, but it is exceptionally good for the comparison of various tile as the methods under which it is performed make its results very reliable.

The opposite is true of the Impact Test. That is, its results are of great practical value in determining the resistance the tile will offer to blows while in use, but the conditions under which it is performed make its results very unreliable. This is due to the difficulty of transmitting all the power of the hammer to the test piece, and to the fact that the piece is struck several times before it is broken. As a result a great many tests must be made to get an average that is anywhere near an accurate value.

It is thus quite evident that a simple relation between the results of the Transverse and Impact Test will be of great value, by allowing the breaking strength under Impact to be figured from the more reliable Transverse Test results, the modulus of rupture. The same is true both of Impact on Plaster Bed and Impact on Knife Edges.

An attempt has been made to determine such a relation in the curves shown in Figures 8 and 9. Here the average values of the various color and make of tiles for the modulus of rupture (abscissae) have been plotted against the unit breaking strength for impact (ordinates) in the *R-f* curve (Fig. 8); for the *C′-f* curve (Fig. 9.) the values of the work per inch of width required to break the tile on Plaster Beds (ordinates) has been plotted against the modulus of rupture (abscissae).

In drawing these curves there are two points evident. One is that the curve must pass through the origin, for when the modulus of rupture is zero the unit breaking strength for impact must also be zero. The other is that whatever curve be drawn it is at most only approximate, hence the simplest curve possible is desirable.

A parabola with its vertex at the origin fits these conditions best. The direction the parabola points depends on the location of the points through which the curve must be drawn. From this the parabola should open toward the right for the *R-f* curve, and upward for the *C′-f* curve.

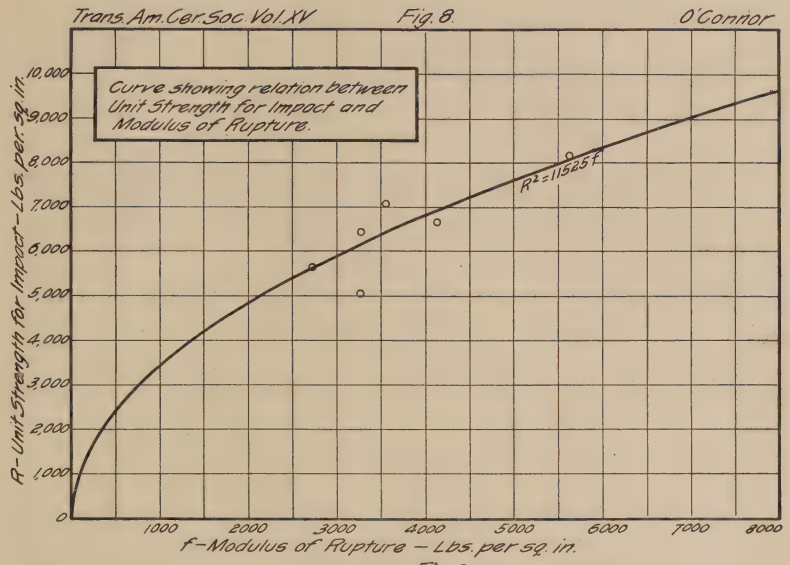
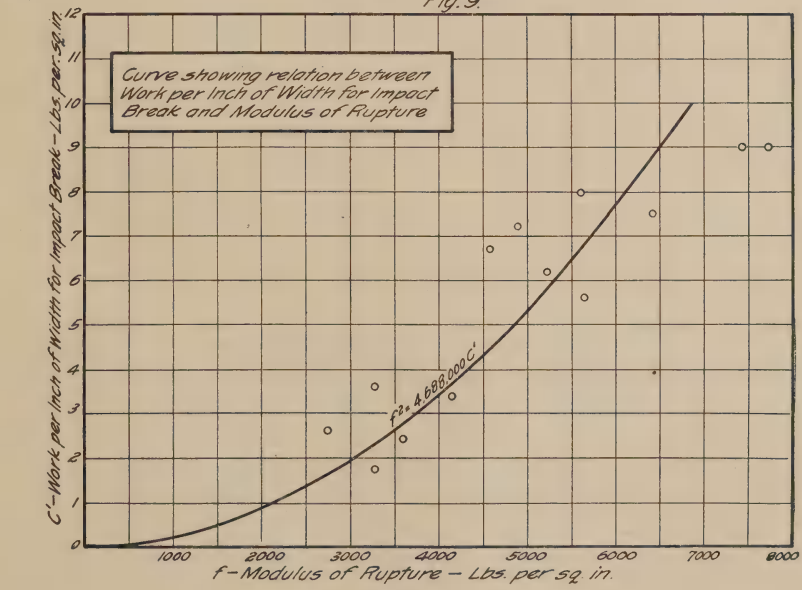

Trans. Am. Cer. Soc. Vol. XV
Fig. 8.
O'Connor
Curve showing relation between Unit Strength for Impact and Modulus of Rupture.
R² = 11525 f
R - Unit Strength for Impact - Lbs. per sq. in.
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1000
2000
3000
4000
5000
6000
7000
8000
f - Modulus of Rupture - Lbs. per sq. in.

Fig. 9.


Curve showing relation between Work per Inch of Width for Impact Break and Modulus of Rupture
f² = 4,688,000 C'
C' - Work per Inch of Width for Impact Break - Lbs. per sq. in.
12
11
10
9
8
7
6
5
4
3
2
1
0
1000
2000
3000
4000
5000
6000
7000
8000
f - Modulus of Rupture - Lbs. per sq. in.

The general equation for these parabola is

$$y^2 = px \tag{10}$$

for the R-f curve, and

$$x^2 = py \tag{11}$$

for the C'-f curve. Substituting the various values for f, R and C' in these equations, solving for p, and then taking the average value of p, we get

$$R^2 = 11{,}525\ f \tag{12}$$

and

$$f^2 = 4{,}688{,}000\ C' \tag{13}$$

Eliminating f between these two equations, we get for a relation between R and C'

$$R^2 = 24{,}970{,}000\ C' \tag{14}$$

It has been suggested that a similar relation be established between the modulus of rupture and porosity. This was attempted but failed, because no sufficient relation of this nature was found to exist, probably because too many factors besides the porosity enter into the strength of the tile.

A relation between the modulus of rupture and resistance to wear might be expected. The abrasion test, though, proved such a failure that no such curve can be drawn here. The writer is confident, however, that there is much to be learned from such a relation and suggests it for a line of future investigation.

CONCLUSIONS

The foregoing tests bring out in an interesting manner the properties of three well known and widely used sets of floor tile, and can probably be used as a basis of what is be to expected of this type of ware.

It seems to the writer that all the tests made are desirable, and the following comments may be regarded as appropriate.

Impact Test. The ball drop is no doubt the best and gives the most uniform results, as well as simulating the type of blow that a floor tile is likely to be subjected to.

Absorption Test. A tile should show low absorption, to prevent

absorption of dirt and also to protect it against frost action, and yet an absorption of 6 or 7 percent does not seem to lower its frost resistance appreciably.

Freezing Test. If floor tile are to be used indoors this test is of no importance, but if they are to be employed for exterior pavements, then frost resistance should certainly be tested.

Transverse Test. It may appear on first thought that this test is of no importance. If the tile were absolutely flat, and rested uniformly in the cement bed, the test might have no value. Such is probably not always the case however, and while the transverse test is the least necessary, it is just as well to make it.

STRENGTH CHANGES NOTED IN LABORATORY DRYING

BY C. H. KERR AND R. J. MONTGOMERY, TARENTUM, PA.

1. Preface. It has been a very common experience in making strength tests of raw clays to obtain very erratic results. A study of these variations led to an investigation of the strength changes accompanying the drying of small clay bars in the laboratory. The first work undertaken was to show the relation between strength and percent of moisture in bars that were practically free from moisture, but this in turn led back to a further investigation of the strength changes taking place at the earlier stages of the drying.

2. Method of Testing. In carrying on the experiment two batches were used: (1) St. Louis fire clay alone; (2) 50 percent St. Louis fire clay and 50 percent grog composed entirely of burned clay of the same sort. About 50 bars of each batch were made (5 in. by $1\frac{1}{4}$ in. by $\frac{3}{4}$ in.), these being molded by hand when mixed to the best working plasticity. By repeated weighings throughout the drying it was possible to break each bar when it had lost a suitable amount of water to place it at any desired point along the curve.

After the bars had reached constant weight drying in the air, some were further dried over sulphuric acid at atmospheric temperature. In this way bars made from the St. Louis clay alone were carried down to 0.5 percent water while originally they had contained 26.6 percent, all figures on moisture content being based upon the dry weight. With the 50 percent grog samples the water content was reduced to 0.1 percent while orginally it had been 17.6 percent. When by its loss in weight any given bar was found to have lost the required amount of water to place it at a desired point on the curve, that bar was broken by the transverse method, the 5 in. bars being supported on knife edges 4 in. apart. From the load required to break the bar the modulus of rupture was calculated from the formula:

$$Sr = \frac{3Pl}{2bd^2}$$

or with $l = 4$ in. the formula becomes

$$Sr = \frac{6P}{bd^2}$$

Sr = modulus of rupture in pounds per square inch.
P = load in pounds required to produce break.
b = breadth of bar.
d = depth of bar.

3. Data. The modulus of rupture tests gave the results shown in the tables below. In Table 1 are given data on the raw clay alone (see Figs. 1 and 2).

TABLE 1.—ST. LOUIS FIRE CLAY
Modulus of Rupture Changes During Drying

PERCENT WATER PRESENT BASED ON DRY WEIGHT	MODULUS OF RUPTURE POUNDS PER SQUARE INCH	PERCENT LENGTH SHRINKAGE	METHOD OF DRYING
26.6			At start
18.8	26	2.8	Air-dried
18.3	43	3.2	Air-dried
17.6	48	3.8	Air-dried
16.4	82	4.8	Air-dried
15.1	121		Air-dried
14.8	173	5.7	Air-dried
12.6	232	6.9	Air-dried
10.9	266	7.6	Air-dried
10.9	309	7.7	Air-dried
10.8	254	8.0	Air-dried
10.8	285	7.5	Air-dried
10.6	251	8.1	Air-dried
10.5	258		Air-dried
10.5	272	8.2	Air-dried
10.2	265	8.3	Air-dried
9.9	243	7.8	Air-dried
9.4	278	7.5	Air-dried
9.1	221	8.2	Air-dried
8.6	331	8.2	Air-dried
8.4	280	7.7	Air-dried
8.2	311	7.8	Air-dried
8.0	288	7.7	Air-dried
7.8	264	7.8	Air-dried

TABLE 1.—ST. LOUIS FIRE CLAY—Continued

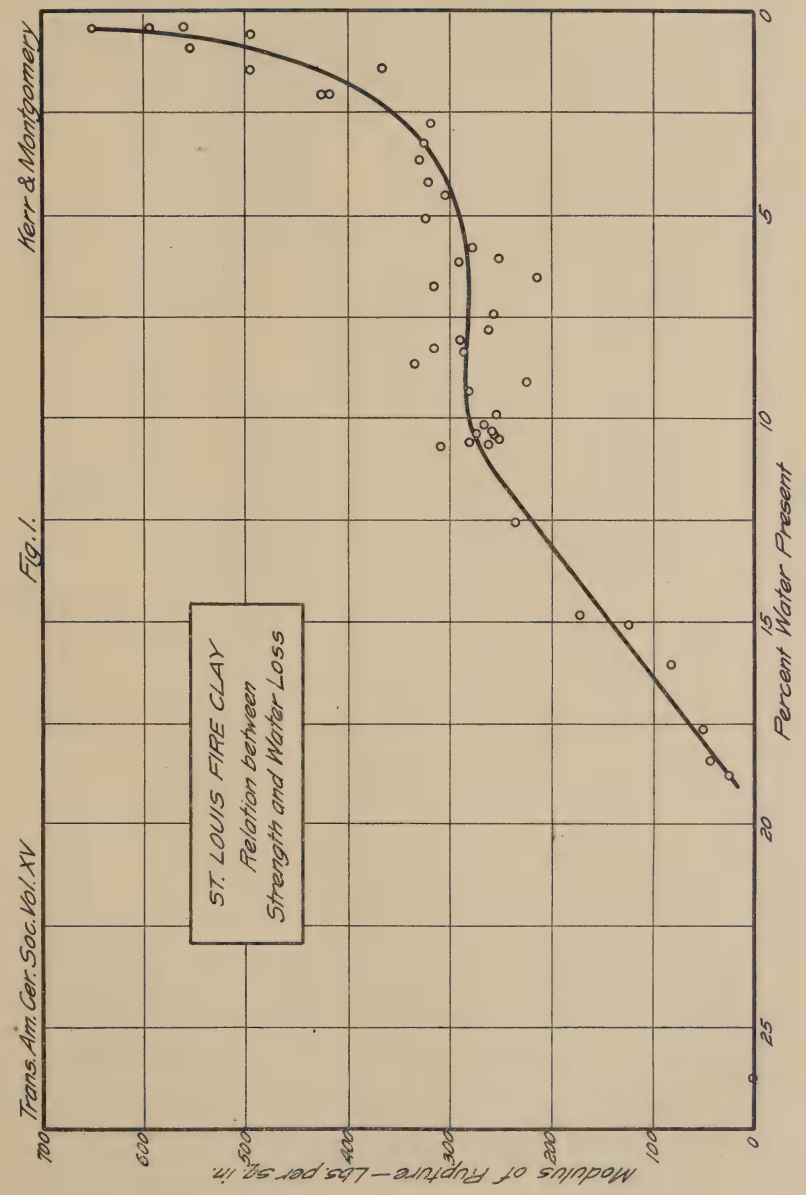
PERCENT WATER PRESENT BASED ON DRY WEIGHT	MODULUS OF RUPTURE POUNDS PER SQUARE INCH	PERCENT LENGTH SHRINKAGE	METHOD OF DRYING
7.4	256	8.0	Air-dried
6.9	311	7.9	Over sulphuric acid
6.7	219	8.2	Air-dried
6.3	291	7.8	Air-dried
6.2	243	7.5	Air-dried
5.9	277	7.8	Air-dried
5.1	323	8.1	Air-dried
4.5	302	7.8	Air-dried
4.2	321	7.8	Air-dried
3.7	333	8.0	Air-dried
3.2	330	7.8	Over sulphuric acid
2.8	320	7.8	Over sulphuric acid
2.1	422	8.1	Over sulphuric acid
2.1	429	8.3	Over sulphuric acid
1.5	494	8.6	Over sulphuric acid
1.4	365	8.2	Over sulphuric acid
1.0	558	7.8	Over sulphuric acid
0.7	492	8.0	Over sulphuric acid
0.5	593	7.8	Over sulphuric acid
0.5	564	8.3	Over sulphuric acid
0.5	645	8.2	Over sulphuric acid
	303	7.8	Over sulphuric acid

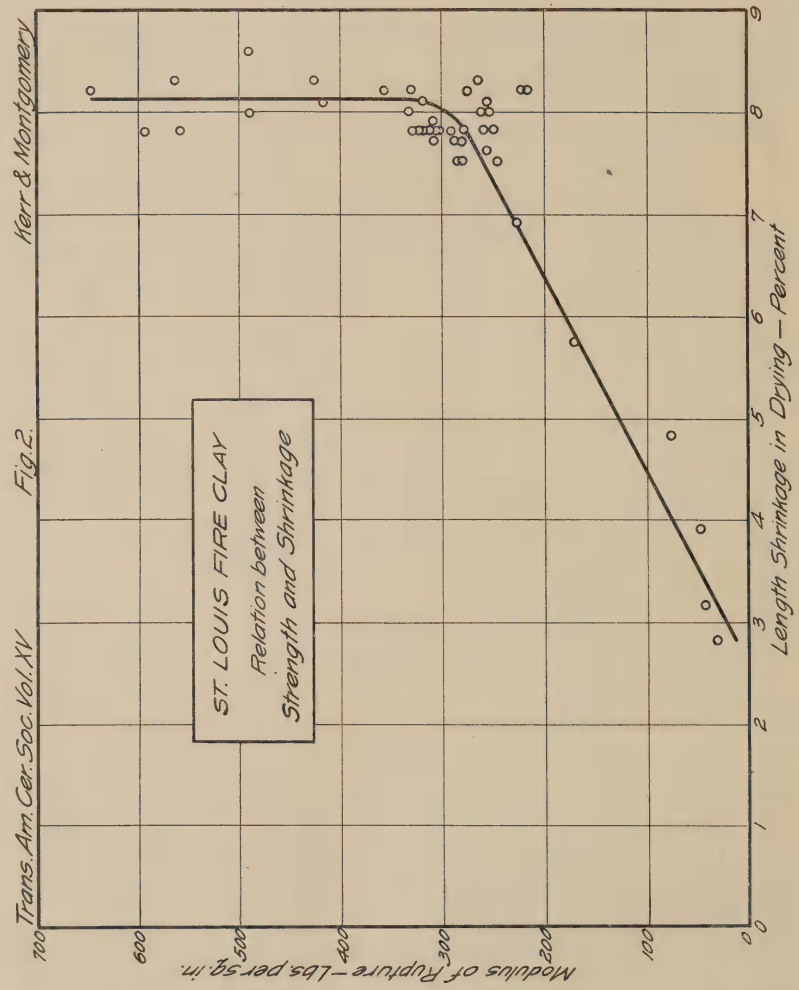
In Table 2 are given data on the modulus of rupture tests using 50 percent St. Louis fire clay and 50 percent grog, the grog being burned material of the same sort (see Figures 3 and 4).

4. Summary. These tests made with small bars dried in the laboratory under accurate control show the following points, the application of the results being limited necessarily to the laboratory drying here described.

1. The maximum strength of St. Louis fire clay alone was reached only when the water content was reduced to less than 1 percent of the dry weight. With 50 percent grog the water content must be reduced to less than 0.5 percent to obtain maximum strength.

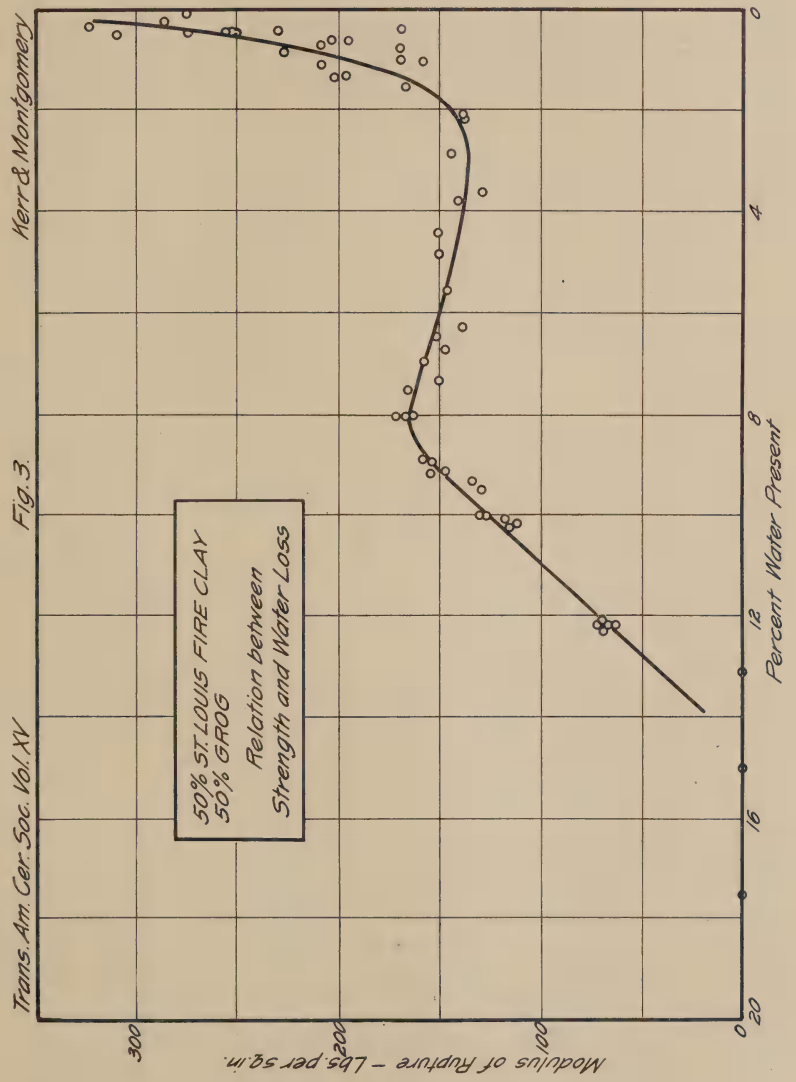
2. The maximum strength of both clay alone and grog mixture was not attained until long after all shrinkage had taken place. At


Trans. Am. Cer. Soc. Vol. XV
Fig. 1.
Kerr & Montgomery
ST. LOUIS FIRE CLAY
Relation between
Strength and Water Loss
Modulus of Rupture — Lbs. per sq. in.
Percent Water Present
0
100
200
300
400
500
600
700
0
5
10
15
20
25



the time shrinkage was completed, the strength for both clay alone and grog mixture was approximately half of the final strength.

3. With the clay alone no measurable strength was obtained until the water content had been reduced from the original amount (26.6 percent) to about 20.0 percent. With further loss of water the strength increased regularly to about 300 pounds per square inch at 11 percent water. With further decrease in water content


Trans. Am Cer. Soc. Vol. XV
Fig. 3
Herr & Montgomery
50% ST. LOUIS FIRE CLAY
50% GROG
Relation between
Strength and Water Loss
Modulus of Rupture – Lbs. per sq. in.
300
200
100
0
0
4
8
12
16
20
Percent Water Present

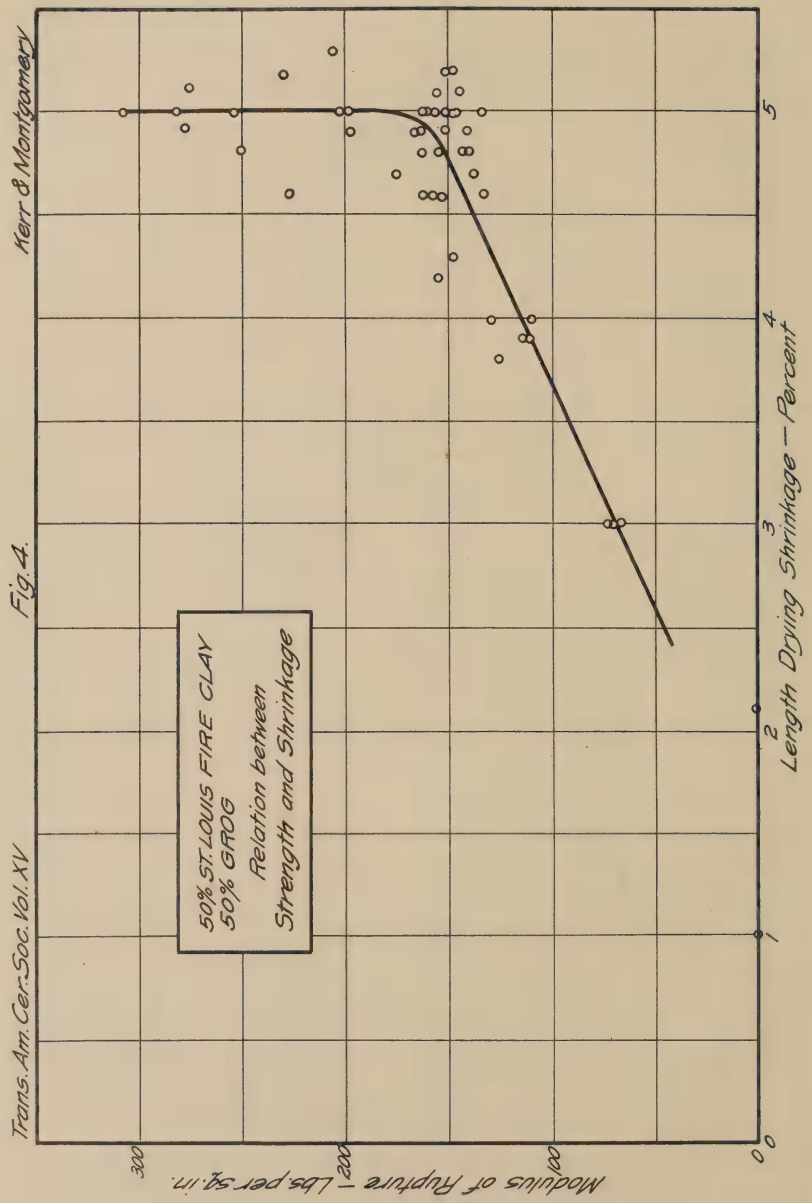

Trans. Am. Cer. Soc. Vol. XV
Fig. 4.
Kerr & Montgomery
50% ST. LOUIS FIRE CLAY
50% GROG
Relation between
Strength and Shrinkage
Modulus of Rupture – Lbs. per Sq. In.
Length Drying Shrinkage – Percent
0
100
200
300
1
2
3
4
5

TABLE 2.—50 PERCENT ST. LOUIS FIRE CLAY, 50 PERCENT GROG

Modulus of Rupture Changes During Drying

PERCENT WATER PRESENT BASED ON DRY WEIGHT	MODULUS OF RUPTURE POUNDS PER SQUARE INCH	PERCENT LENGTH SHRINKAGE	METHOD OF DRYING
17.6			At start
15.0		1.0	Air-dried
13.2		2.1	Air-dried
12.3	70	3.0	Air-dried
12.2	68	3.0	Air-dried
12.2	66	2.9	Air-dried
12.2	69	3.0	Air-dried
12.1	70	3.0	Air-dried
10.3	116	3.9	Air-dried
10.2	111	4.0	Air-dried
10.1	118	3.9	Air-dried
10.0	127	3.8	Air-dried
10.0	129	4.0	Air-dried
9.6	129	4.6	Air-dried
9.5	133	4.7	Air-dried
9.2	155	4.8	Air-dried
9.2	147	4.3	Air-dried
8.9	154	4.2	Air-dried
8.9	159	4.6	Air-dried
8.0	171	4.7	Air-dried
8.0	164	4.9	Air-dried
8.0	166	4.6	Air-dried
7.6	165	4.8	Air-dried
7.4	150	4.9	Air-dried
7.0	157	5.0	Air-dried
6.9	147	5.0	Air-dried
6.5	152	4.6	Air-dried
6.3	138	4.8	Air-dried
5.5	146	5.2	Air-dried
4.8	150	5.0	Air-dried
4.5	150	5.2	Air-dried
3.8	140	5.1	Air-dried
3.7	129	5.0	Air-dried
3.4	136	4.8	Air-dried
2.8	146	5.0	Air-dried
2.2	137	4.9	Air-dried
2.1	138	4.8	Air-dried
1.7	166	4.8	Air-dried
1.4	196	5.0	Air-dried
1.4	201	5.0	Air-dried

TABLE 2.—50 PERCENT ST. LOUIS FIRE CLAY, 50 PERCENT GROG—Continued

PERCENT WATER PRESENT BASED ON DRY WEIGHT	MODULUS OF RUPTURE POUND PER SQUARE INCH	PERCENT LENGTH SHRINKAGE	METHOD OF DRYING
1.2	210		Over sulphuric acid
1.1	168	4.9	Air-dried
1.1	158	5.1	Air-dried
0.9	168	5.0	Air-dried
0.9	225	4.6	Over sulphuric acid
0.8	210	5.3	Air-dried
0.7	194	4.9	Air-dried
0.7	204		Over sulphuric acid
0.5	256	5.0	Air-dried
0.5	228	5.2	Over sulphuric acid
0.5	254		Over sulphuric acid
0.5	271	5.1	Over sulphuric acid
0.5	250	4.8	Over sulphuric acid
0.5	312	5.0	Over sulphuric acid
0.4	323		Over sulphuric acid
0.4	283	5.0	Air-dried
0.4	167	5.0	Air-dried
0.3	282		Over sulphuric acid
0.1	271		Over sulphuric acid
0.1	271	4.9	Over sulphuric acid

from 11 percent to about 3 percent there was no change in strength. Below 3 percent water the strength increased rapidly to about 300 pounds per square inch when the water content was under 0.5 percent.

4. With the 50 percent grog mixture no measurable strength was found until the water content had been reduced from the original figure (17.6 percent) to about 12 percent. Further decrease in water content was accompanied by regular increase in strength to about 155 pounds per square inch at 8 percent water. This was a maximum point. Further decrease in water caused a slight *decrease* in strength down to about 3 percent water when the strength was about 135 pounds per square inch. Decreasing the water content from 3 percent to about 1.5 percent gave small increases in strength to about 1.65 pounds per square inch at 1.5 percent water. Below 1.5 percent water the strength increased rapidly with decrease in water content to about 300 pounds per square inch at 0.1 percent water.

A VOCATIONAL SCHOOL FOR CLAY WORKERS

GEORGE C. GREENER, E.M. IN CER. BOSTON, MASS.

Have any of you who are gathered here ever stopped to realize what a small proportion of our much prized public school education reaches the young men and women who are forced into industry for a livelihood?

Have you ever stopped to consider that your responsibility to these people does not cease when you give them an opportunity to work and pay your school taxes?

Perhaps one of your problems is that of the unskilled industrial worker. Let me tell you of a school that solves this problem.

It is situated in a clay working and ceramic center. Large sums of money were not spent on its exterior. It is of the simplest American architecture of red brick and white terra cotta trimmings. Set among the trees with a foreground of wellkept lawns and shrubs, it made a picture. You might take this building for a Carnegie library without the familiar inscription, had you not known it was designed for laboratories and workshops.

In striking contrast was the pottery I visited the other day. I waded through mud, past barrel upon barrel of waste material to reach the office. This factory produces some of the highest grade of American art ware, but its market is local and little of its product ever crosses the water.

Have Japanese employers gone ahead of American employers in learning that environment plays an important part, in the quality of a workman's output? They build their potteries in gardens and give their workers the most inspiring surroundings. Is this the reason we import tons of high grade Japanese wares to fill the gap left by our manufacturers?

The young men and women entering this school at a quarter to eight in the morning surprised me. They were not a bedraggled group of uninteresting factory hands beginning the day by half wishing it was over. These young people, neatly and simply dressed, were bright and animated looking as if something pleasant awaited them.

The director, whom I met on entering, impressed me by the

largeness of his nature and the warmth of his personality. He was a man well connected with business interests and had owned a large terra cotta plant. He showed by his convincing and general manner how he had obtained the large financial support and hearty coöperation of all the manufacturers in the community. He was the rare combination of teacher, technician, business executive and thorough gentleman. The community's great interest in the school he attributed to their business foresight. "They appreciate the increased efficiency and intelligent interest of the workers taught in this school." He said, "this means naturally a distinct financial return to the manufacturer who finds the loss due to disinterested and careless handling of wares largely eliminated.

"The employer's interest is further enlisted by allowing them to inspect the school, to receive help in regard to their particular problems and to assist in the choice of men for teachers. They occasionally advise us on courses of instruction. In return we expect them to supply within reason, models, tools, machinery, raw material and important data."

The director laid before me the plan of the school and its schedule. The morning was divided into hour periods—two for shopwork, two for class or round table discussions and one hour for luncheon. The afternoon was similarly divided.

We went into one of the class rooms which presented an unusual sight for the traditional school room. My eye caught a large mat glazed vase in the center of the room, around which the class had gathered. They had not started at the A B C's of glaze making but had begun at the end. This perfect glaze was given to them in working formula, to reproduce on a perfect piece of ware. Here began the discussion, questions and answers on the geology of the feldspar, the china clay, the ball clay, the copper oxide and the iron oxide that were all component parts of this glaze. The winning of the clays, the preparation of the materials, the body making, the glazing process and the firing came in just so far, as they were related to the piece of ware which some of this group of young people had produced.

Mathematics, physics and chemistry in abstract are sheer waste of time with these people and only the calculations, physics and chemistry that relate directly to the problems in hand, are taken

up. This glaze was further studied in each component part and each alteration studied in its effect on a perfect piece.

Had I been there at other days I should have seen the same instructional methods used on perfect samples of wall tiles, bricks and stone wares. These products were manufactured in the neighborhood.

The next two hours of the morning were spent in the admirably designed workrooms and studios. Here the work was wholly individual. One youth, whose scholarship had been paid by the potter's union, was enthusiastically making dry pressed tile; two were busy at mold making, another lad was making saggers, two more were loading a small kiln with decorated vases, each one of individual design and workmanship. In one corner the jigger's and potter's wheel were busily engaged. The atmosphere was of real earnestness and cheerfulness. Everywhere the moral effect of good work showed clearly through their radiant faces exemplifying the instructor's words, "We must inspire them with a keen satisfaction that comes from the thoroughness of work." He, like the others of the teaching staff, had been a successful foreman in a large clay working plant.

The idea of correlation prevailed in the studios as well as in the class rooms and shops. Original designs were being adapted to definite shapes and forms. Interlacing and repeating designs were being worked out for floor tiles to be laid in the school corridors. Two girls were modeling spandrels for polychrome terra cotta to be placed over the entry of the school.

If we attempt the monumental task of educating the users of ceramic art in this country, we must begin by educating the producers and workers of the art. Why we import tons upontons of high grade ceramic work from Japan is not surprising when we consider what our factories are willing to put on the market. Vases are decorated with lions and elephants regardless of line, form or color. Dinnerwares, not only tawdry and clumsy are made, but with as little durability as the market will stand.

In another attractive room a group of healthy young people were taking notes on hygiene and first aid to the injured from a leading physician. This was to teach the pupils a rational way of living, physical and intellectual, with special consideration

for workshop sanitation as well as personal hygiene. Special emphasis is placed on the structure and care of the human body. Nourishment, food values, dwelling houses and clothing, work and recreation, gymnastics and open air exercise, trade influences injurious to health, more especially the injurious effect of dust and gases, lead poison, its effect and cure are all studied. First aid for burns, scalds, heat prostrations, etc., respiration and blood circulation are given in shop terms.

On another day trade history is taught. Business methods and forms, time sheets and records in connection with local factories are lectured on in regard to their meaning and efficiency. At noon, instead of floor corners and benches filled with tired workers eating indigestible lunches, I found a cheerful lunch-room where a wholesome luncheon was served at cost to the student. This room like all the others had been decorated by the different classes.

The afternoon I spent in one of the tile factories and found, carrying on various occupations, many of the same people that I had seen at the classes in the morning. Their eager interest in their work, their ambition and the understanding of their relation to the work of the whole plant easily distinguished them from those who had not been especially trained.

One of the instructors whom I saw in the morning was here with a new group of boys, the other half of the shop's scholars.

For two weeks one corps of workers attend school in the morning while the other corps are in the factory. They return to work in the afternoon allowing the morning factory corps to study. This arrangement is reversed every two weeks.

All groups meet for three evenings a week. During the extreme busy season classes are not held, but all scholars return to work, thereby furnishing the required "extra" help of unusual capability. I was glad to learn that the school gave to groups of men during their layoff on account of dull season, etc., short courses in brush decoration, glazing, sagger making, kiln setting, mold making, etc.

When I inquired how these scholars could afford only to work half time I was assured that the results had so justified the loss of time in the factory that most of them were willing to make the temporary sacrifice for the larger gain. In some cases, the scholars who could not afford to lose any time in the shop received state aid. Does this seem unreasonable when we consider that the state gives

over $500 to every person who, for economic reasons principally, goes through our university?

Some boys on account of their improvement were remunerated by their firms, some were repaid by the union organizations who heartily supported such a worthwhile training.

In the evening I returned to the school where all were assembled in a modern lecture hall to hear an educational talk on sex hygiene. Next came moving pictures illustrating processes, etc., one reel was the winning and preparation of Florida Kaolin, another was a trip through the Sèvres porcelain factory.

The social secretary informed me that on other evenings there were profitable round table discussions of trade unions, and club meetings for the study of civics and government. Occasional social gatherings, athletic and gymnastic meets were on the schedule too. The evening work is recreational and social. On Sundays the library with its technical as well as popular books and magazines and the school museum are open to the scholars and their friends. In the afternoon music and lectures on current social topics with open discussion are given.

It is futile and superficial, if not harmful to give work that requires constructive and creative thinking at the end of the working day.

a. The main features of this school, therefore, are practical work, which has meaning to the student, is made the center of interest.

b. The active sympathy and coöperation of the state, of employers of trade unions and leagues are secured—a mutual combination of education and industry.

c. The time of instruction is sufficient in amount and excellent in quality to attract and hold industrial workers.

d. Every effort is made to make the scholar a discriminating user as well as efficient producer, to make him a man and a citizen who feels the responsibility of his environment. To make him fit in body and alert in mind and to prepare him for the rational enjoyment of his leisure time as well as fit him for earning a comfortable and decent living.

William Morris, one of the greatest of workmen emphatically said, "No excellent or beautiful work could come from overworked and unenlightened laboring people." Therefore, gentlemen, if you care about raising the standards of the American ceramic

products, if you, as American citizens care for the welfare of your brother, the young industrial worker, see to it that you give him, not only the opportunity for work but the chance to grow in his work and his life.

DISCUSSION WRITTEN AFTER READING THE PAPER

Mr. Hope: Mr. Greener calls attention to one of the greatest problems that confronts the manufacturer of today. Poor workmanship is, I believe, due almost entirely to lack of interest in the work, at least far more than to any want of ability on the part of the workers. And yet, is it to be wondered that so many are careless and indifferent to their work and the interests of their employers where no interest is shown in return? It is a much-to-be-regretted fact that when the state or federal legislatures consider such measures as workmen's compensation or regulation of child labor, the great majority of employers immediately oppose, with all the strength that they can muster, any attempt to improve working conditions if such improvement means financial sacrifice on their part. Such a school as Mr. Greener describes would go far to improve the situation in the locality where it existed; and although the writer is a little dubious about the proposed order of instruction, the main ideas outlined have very much to commend them. The attitude of labor organizations to such an institution would be problematical, though there is no apparent reason why it should not have full support in that quarter also, as it would not be a trade school, but rather one in which those, many of whom would in any case learn a trade through a regular term of apprenticeship in the factory, would have an opportunity for learning the relationship of their own work to that of the rest of the factory, thus, by enlarging their interests, increasing their efficiency, and in many cases fitting them for better positions.

Speaking for the pottery trade, it is safe to say that never before was there more need for intelligent practical men, men who know how ware should be made, and who can both make a plate and figure a formula. It is not enough to have sufficient knowledge to change a glaze if one cannot fire a kiln; and the writer is firmly convinced that efficient men for the pottery industry will never be turned out by the ceramic schools till this fact is recognized and the condition met.

THE RELATION BETWEEN COMPOSITION AND DENSITY OF FELDSPATHIC PORCELAINS

BY AMOS P. POTTS AND HARRY F. KNOLLMAN

INTRODUCTION

This investigation is the direct result of two investigations of a similar nature published in Vol. 13, *T. A. C. S.* One of these, entitled "Some Coefficient of Expansion Data on Porcelain Made from European Materials," by A. S. Watts, contains the results of Mr. Watt's work in the laboratory of a German University; and the other paper, by Ross C. Purdy and one of the present writers, contains results obtained in the laboratory of the Ohio State University. In replying to a note written by Mr. Watts discussing this latter paper, one of the present writers took occasion to plot the data for similar series in each investigation on the same diagram in order to show the exact relation between the data of these two separate and distinct investigations (see Plate 1, p. 463, Vol. 13, *T. A. C. S.*). This figure opened up such an interesting line of thought, not only as regards the effect of composition, but also as to that of heat treatment, that it was decided to repeat the work on a much larger scale and with test pieces burned with different heat treatments.

Mr. Watts found that his results checked Seger's theory as to the function of these minerals in causing or preventing crazing. The investigation with American materials, covering as it did a much larger area, checked him only in part and the principal conclusion in the larger paper was that the structure of the body was more of a factor in influencing the coefficient of expansion than was the composition.

Regarding the relation between composition and the structure of white ware bodies, Seger has written as follows, page 478: "In the work done so far for instance, there is found nothing about the relation in which the porosity of the dried or burned clay stands to the amount of non-plastic contents." Again on page 506 we find the following statement: "Not only for the highest temperatures, but also for the lower degrees of heat customary in practice, does

the amount of feldspar present furnish a valuable index as to the course which the vitrification will take, and especially if the quartz content is considered with it. . . . . its (the quartz) effect commences with the fusion of the feldspar which, when in the liquid state is capable of dissolving silica, as is well known and in this manner the quantity of the fluxes will be increased." On page 508, we find this statement: "All factors, feldspar, quartz and clay substance are therefore entitled to equal consideration and the various influences now opposing, now augmenting each other cannot be precisely expressed by one value, refractory quotient; even if it can be made to coincide with the facts in some cases. On page 511 is this statement: "The quartz does not enter into chemical reaction until far above the fusing point of feldspar, which dissolves the quartz as we have seen and thus increases the bulk and becomes more fluid."

Thus, even though Seger appreciated the influence of the various constituents of a porcelain body upon its physical properties, we fail to find any data sufficiently complete to warrant definite conclusions regarding the relation of these physical properties to one another; such as coefficient of expansion and structure.

Turning now to the *T. A. C. S.*, we are a little more successful. In Vol. 12, page 628, is a paper, entitled "A Study of the Vitrification Range and Di-electric Strength of Some Porcelains," in which is given a number of curves and considerable data on vitrification as determined by absorption, specific gravity, and the di-electric strength of porcelains made from four different clays and covering a wide range of composition as to feldspar, clay, and flint content. But the weak part of this paper for our study is that the vitrification data are based entirely upon the open pores, whereas in the work published in Vol. 13, *T. A. C. S.*, it has been shown to be important to ascertain the total porosity, since the presence of sealed pores seemed to be as effective in raising the coefficient of expansion as was the absence of complete vitrification.

Object of Investigation. Therefore it is the object of this investigation to ascertain the progress of vitrification in a number of white ware body compositions.

PREPARATION OF SAMPLES

The Present Investigation. *a.* The field included within the limits of this investigation contains all those body compositions within the following limits.

Feldspar	0 to 50 percent
Clay	20 to 90 percent
Flint	10 to 80 percent

b. The particular mixtures tested are indicated on the triaxial diagram (Fig. 1) and are shown on the data sheet (Table 1). Materials used, their proportions and their chemical analyses are also shown on the tabulated data sheets, Tables I and II.

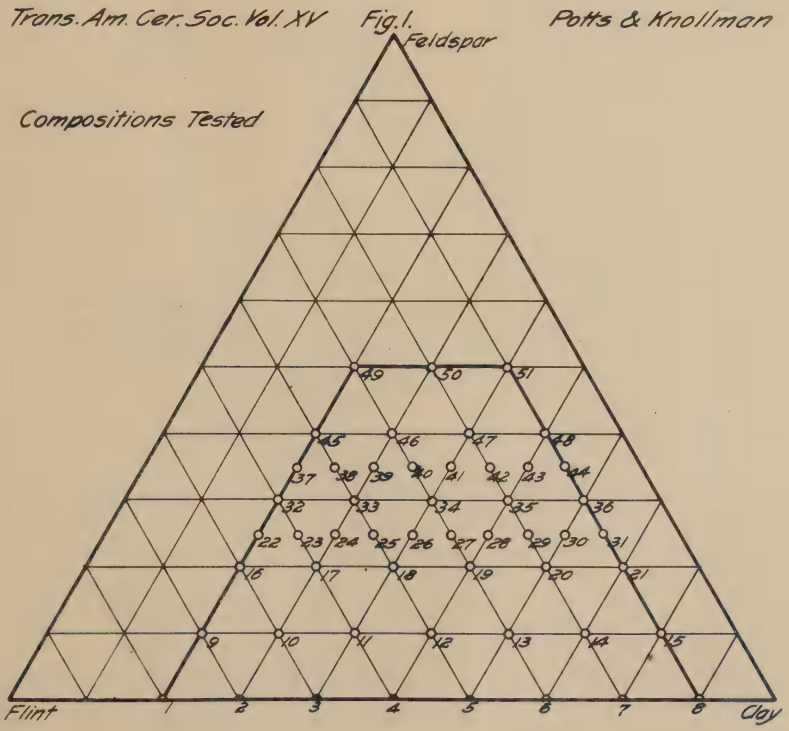


TABLE I—PERCENTAGE COMPOSITION AND BATCH WEIGHTS

BODY NO.	FELDSPAR	FLINT	CLAY	FELDSPAR	FLINT	GEORGIA—58	ENGLISH—7	DILLSBORO	JOHNSON AND PORTER—9	MANDLE AND SANT—9
	percent	*percent*	*percent*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
1	0	80	20	0	16	1.0	1.0	1.0	0.50	0.50
2	0	70	30	0	14	1.5	1.5	1.5	0.75	0.75
3	0	60	40	0	12	2.0	2.0	2.0	1.00	1.00
4	0	50	50	0	10	2.5	2.5	2.5	1.25	1.25
5	0	40	60	0	8	3.0	3.0	3.0	1. 0	1.50
6	0	30	70	0	6	3.5	3.5	3.5	1.75	1.75
7	0	20	80	0	4	4.0	4.0	4.0	2.00	2.00
8	0	10	90	0	2	4.5	4.5	4.5	2.25	2.25
9	10	70	20	2	14	1.0	1.0	1.0	0.50	0.50
10	10	60	30	2	12	1.5	1.5	1.5	0.75	0.75
11	10	50	40	2	10	2.0	2.0	2.0	1.00	1.00
12	10	40	50	2	8	2.5	2.5	2.5	1.25	1.25
13	10	30	60	2	6	3.0	3.0	3.0	1.50	1.50
14	10	20	70	2	4	3.5	3.5	3.5	1.75	1.75
15	10	10	80	2	2	4.0	4.0	4.0	2.00	2.00
16	20	60	20	4	12	1.0	1.0	1.0	0.50	0.50
17	20	50	30	4	10	1.5	1.5	1.5	0.75	0.75
18	20	40	40	4	8	2.0	2.0	2.0	1.00	1.00
19	20	30	50	4	6	2.5	2.5	2.5	1.25	1.25
20	20	20	60	4	4	3.0	3.0	3.0	1.50	1.50
21	20	10	70	4	2	3.5	3.5	3.5	1.75	1.75
22	25	55	20	5	11	1.0	1.0	1.0	0.50	0.50
23	25	50	25	5	10	1.25	1.25	1.25	0.625	0.625
24	25	45	30	5	9	1.50	1.50	1.50	0.75	0.75
25	25	40	35	5	8	1.75	1.75	1.75	0.875	0.875
26	25	35	40	5	7	2.00	2.00	2.00	1.000	1.000
27	25	30	45	5	6	2.25	2.25	2.25	1.125	1.125
28	25	25	50	5	5	2.50	2.50	2.50	1.250	1.250
29	25	20	55	5	4	2.75	2.75	2.75	1.375	1.375
30	25	15	60	5	3	3.00	3.00	3.00	1.500	1.500
31	25	10	65	5	2	3.25	3.25	3.25	1.625	1.625
32	30	50	20	6	10	1.00	1.00	1.00	0.50	0.50
33	30	40	30	6	8	1.50	1.50	1.50	0.75	0.75
34	30	30	40	6	6	2.00	2.00	2.00	1.00	1.00
35	30	20	50	6	4	2.50	2.50	2.50	1.25	1.25
36	30	10	60	6	2	3.00	3.00	3.00	1.50	1.50
37	35	45	20	7	9	1.000	1.000	1.000	0.500	0.500
38	35	40	25	7	8	1.25	1.25	1.25	0.625	0.625

TABLE I—Continued

BODY NO.	FELDSPAR	FLINT	CLAY	FELDSPAR	FLINT	GEORGIA—58	ENGLISH—7	DILLSBORO	JOHNSON AND PORTER—9	MANDLE AND SANT—9
	percent	*percent*	*percent*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*	*pounds*
39	35	35	30	7	7	1.50	1.50	1.50	0.750	0.750
40	35	30	35	7	6	1.75	1.75	1.75	0.875	0.875
41	35	25	40	7	5	2.00	2.00	2.00	1.000	1.000
42	35	20	45	7	4	2.25	2.25	2.25	1.125	1.125
43	35	15	50	7	3	2.50	2.50	2.50	1.250	1.250
44	35	10	55	7	2	2.75	2.75	2.75	1.375	1.375
45	40	40	20	8	8	1.00	1.00	1.00	0.50	0.50
46	40	30	30	8	6	1.50	1.50	1.50	0.75	0.75
47	40	20	40	8	4	2.00	2.00	2.00	1.00	1.00
48	40	10	50	8	2	2.50	2.50	2.50	1.25	1.25
49	50	30	20	10	6	1.00	1.00	1.00	0.50	0.50
50	50	20	30	10	4	1.50	1.50	1.50	0.75	0.75
51	50	10	40	10	2	2.00	2.00	2.00	1.00	1.00

TABLE II—ANALYSIS OF MATERIALS

ULTIMATE

	OHIO SILICA CO.'S FLINT	MAINE FELDSPAR	MACON GEORGIA "WASHED" KAOLIN NO. 58	ENGLISH CHINA NO. 7 NO. 89	DILLSBORO KAOLIN NO. 90	JOHNSON AND PORTER NO. 9 NO. 98	MANDLE AND SANT NO. 9 NO. 86	TOTAL CLAY AS USED
SiO_2	99.18	71.75	44.90	47.37	45.78	51.20	48.53	46.98
Al_2O_3		16.70	38.49	37.85	36.79	32.10	32.72	36.39
Fe_2O_3	0.26	0.14	0.76	0.31	0.50	0.73	0.70	0.57
TiO_2	0.01	0.03	1.20	0.04	0.06	1.40	1.30	0.66
CaO	0.01	0.25	trace			0.13	0.20	0.08
MgO	0.01		trace	trace				trace
K_2O		8.59	0.30	1.40	0.58	0.69	1.03	0.79
Na_2O		2.99		0.14		0.10	0.47	0.11
Loss on ignit on	0.11	0.35		12.60	16.49	13.75	14.90	14.65
Hyg. H_2O			0.85					
Total H_2O			14.35					
Total	99.58	99.80	100.85	99.71	100.20	100.10	99.83	100.23
DETERMINED RATIONAL								
Clay		3.5	98.0	90.0	93.3	87.0	88.7	92.3
Feldspar		75.5	2.0	10.0	3.5	3.0	8.0	5.3
Flint	99.18	21.0			3.2	10.0	3.3	2.5

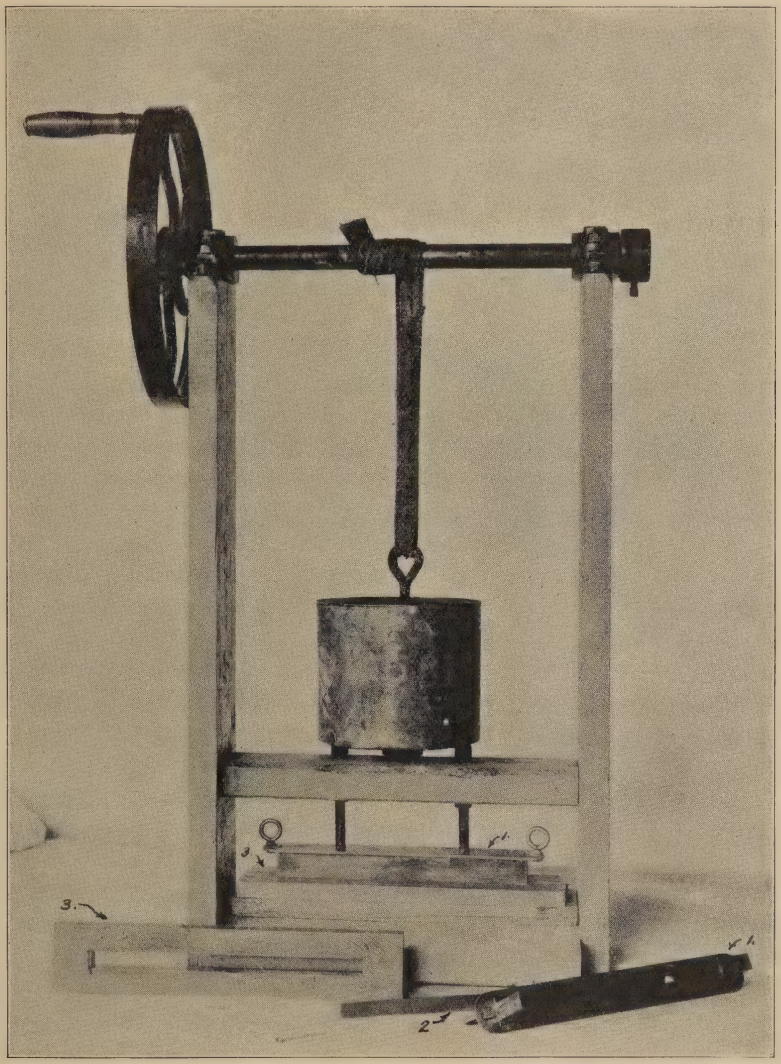
Preparation of the Bodies. The ingredients were weighed into paper bags and the weights checked, then when all of the ingredients had been weighed up the total weights were checked. Twenty pounds of each body were made.

When all of the bodies had been weighed and checked, the contents of each bag were dumped into ten-gallon stoneware crocks with about two gallons of water and allowed to soak over night. They were then blunged by hand and screened, first through a 40 and then through a 100-mesh screen; and the residue, consisting mostly of wood fiber and large particles of quartz, having been thoroughly washed, was thrown away.

The blunged bodies were then allowed to settle, the supernatent liquid being siphoned off from time to time, until the mass had assumed the condition of a very thick slip, in which condition, it was again carefully blunged, cast in a muslin lined wooden frame on a muslin covered plaster slab and allowed to stand until it had assumed about the consistency desired in clay for juggering.

Making the Trial Pieces. For the purposes of obtaining coefficient of expansion data, trial pieces twenty-five centimeters long when fired were desired. A biscuit cutter twelve inches long by three-quarters of an inch wide was designed and made by the Ceramic Supply Company of Columbus, Ohio. As used, the cutter consisted of three parts: first, the cutter proper; second, a steel plunger; third, a steel die. The cutter proper consisted of a $\frac{1}{8}$-inch steel plate 2 inches by 15 inches, to which was soldered and riveted the copper cutting edge. This cutting edge was about $2\frac{1}{2}$ inches high and bent so as to cut a brickette 12 inches by $\frac{3}{4}$-inch. In the steel plate two $\frac{1}{2}$-inch holes were placed 3 inches each side of the middle, for the passage of the $\frac{3}{8}$-inch iron rods of the compression machine, as shown by the illustration, Figure II, and to the ends of the plate were bolted metallic loops used in removing the cutter from the die. The plunger was a piece of $\frac{1}{8}$-inch steel of a size to fit just inside the cutter. The die was a steel block 3 inches wide by 15 inches long and $\frac{3}{4}$-inch thick, slotted to receive the cutter.

In making a trial piece, the plunger was placed within the cutter, and then by means of the cutter a portion of clay was cut from the slab as cast on the muslin covered plaster block. The cutter was then placed in the steel die which rested on a muslin covered


3.
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piece of board, (18 inches by 4 inches by 1 inch) and the whole placed in the compression machine in such a manner as to permit the rods to pass through the holes in the top of the cutter and rest on the plunger, as shown by the illustration, Figure II. The clay within the cutter was then compressed by turning the handle on the wheel attached to the winding drum, twice through an angle of 45 degrees and each time releasing it. Each brickette was thus given as nearly as possible the same treatment, first a static pressure of 14 pounds per square inch and then two impact stresses whose values were not determined, but which as has been explained were as nearly as possible equal for all the brickettes.

Then, while the weight rested on the plunger,—the cutter was raised by means of rods thrust through the loops and the plunger and excess clay were cut off by drawing a fine wire across the top of the die. The weight was then raised and the brickette removed from the frame as follows: The cleaned plunger was laid on the brickette and as the die was supported by the fingers of each hand of the operator, he, by the pressure of his thumbs on the plunger, forced the plunger and brickette out of the die, allowing them to drop gently onto a tissue paper covered pallet. It was hoped in this manner to obtain brickettes from the various compositions having as nearly as possible the same structure. It was found that if the pieces were forced out so that they rested on the side which had been cut by the wire and allowed to dry in this position, they would do so without warping, but that if they were dried with the cut side up they had a tendency to curl up at the ends.

About forty trial pieces of each body were made in this manner and dried on pallets in the laboratory. When in the leather-hard state, the trials were trimmed and placed on shelves in a locker to complete their drying and to remain until required for burning.

Burning. Four trials of each body were burned at each of the following heat treatments:—

Cone 2	19 hours
Cone 4	23 hours
Cone 8	28 hours
Cone 12	36 hours

For each burn, four 11 inches by 21 inches by 7 inches oval saggers were used, one trial from each body being placed in each sagger. The trials were separated by means of coarse bit-stone. The

saggers were placed in two bungs, each two saggers high, in the No. 3 kiln of the Ohio State University Ceramic Laboratory. In order to control the heat treatment and to know exactly what treatment each sagger received, cone pats each containing four cones, one below and two above the cone desired, were placed in each end of each sagger, and as sight cones, plaques containing five cones, one below and three above the cone desired, were placed beneath and also on top of each bung. No sagger of trial pieces was used unless the same cone was down in both ends. It frequently happened that there would be from a half to a cone difference from end to end of a sagger, but all such trials were thrown out and if necessary a new burn made.

When four trials of each body at each heat treatment were obtained they were sorted, the straightest being reserved for the coefficient of expansion and the next being reserved for obtaining porosity data.

BULK SPECIFIC GRAVITY

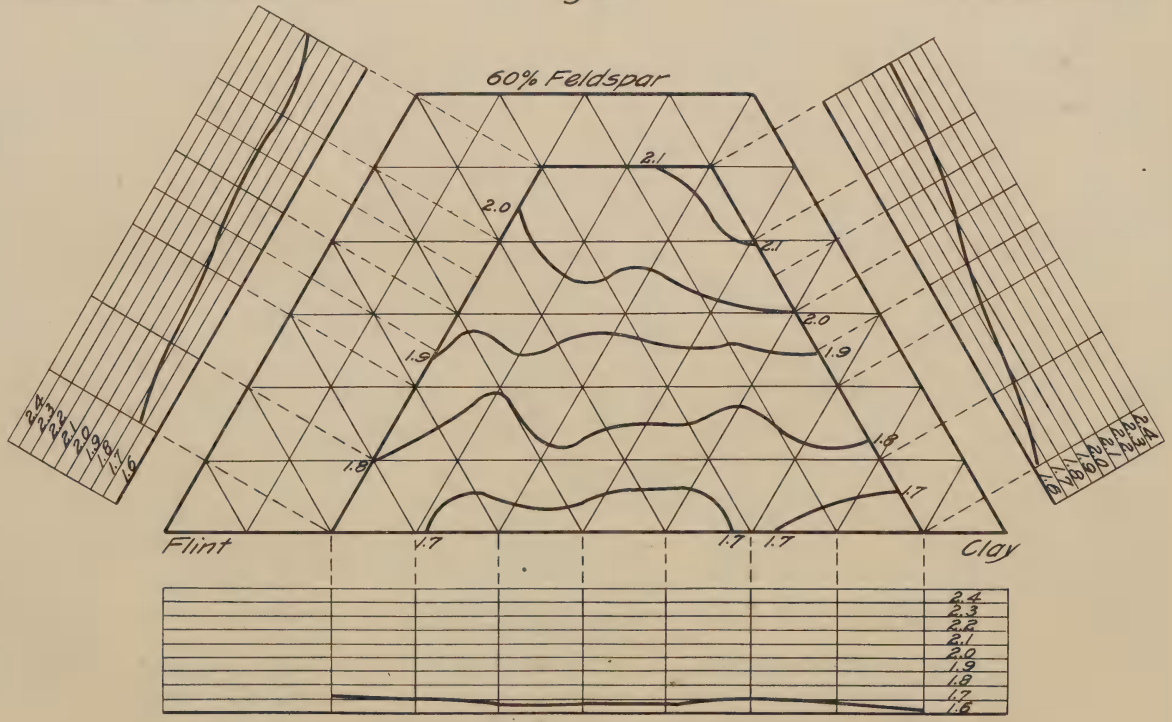
Definition. By bulk specific gravity we mean the dry weight of the burned brick divided by its exterior volume.

Method of Obtaining Bulk Specific Gravity. Bulk specific gravity data was obtained as follows: a piece about three inches long was broken from each of the pieces set aside for this purpose, weighed and immersed in water with one face exposed for forty-eight hours. These pieces were then weighed wet, and the weights recorded as wet weight. The piece was then completely immersed in a beaker of distilled water, and the weight recorded as suspended weight. The wet weight minus the suspended weight equals the exterior volume (see Bull. 9 Ill. G. S.). The bulk gravity is then obtained by dividing the dry weight by the exterior volume. The data so obtained will be found in the accompanying tables (Table III) and also plotted on the triaxial diagrams (Figs. 3, 4, 5 and 6).

Discussion. For the purpose of study, the data has been assembled on triaxial diagrams, one diagram for each heat treatment.[1]

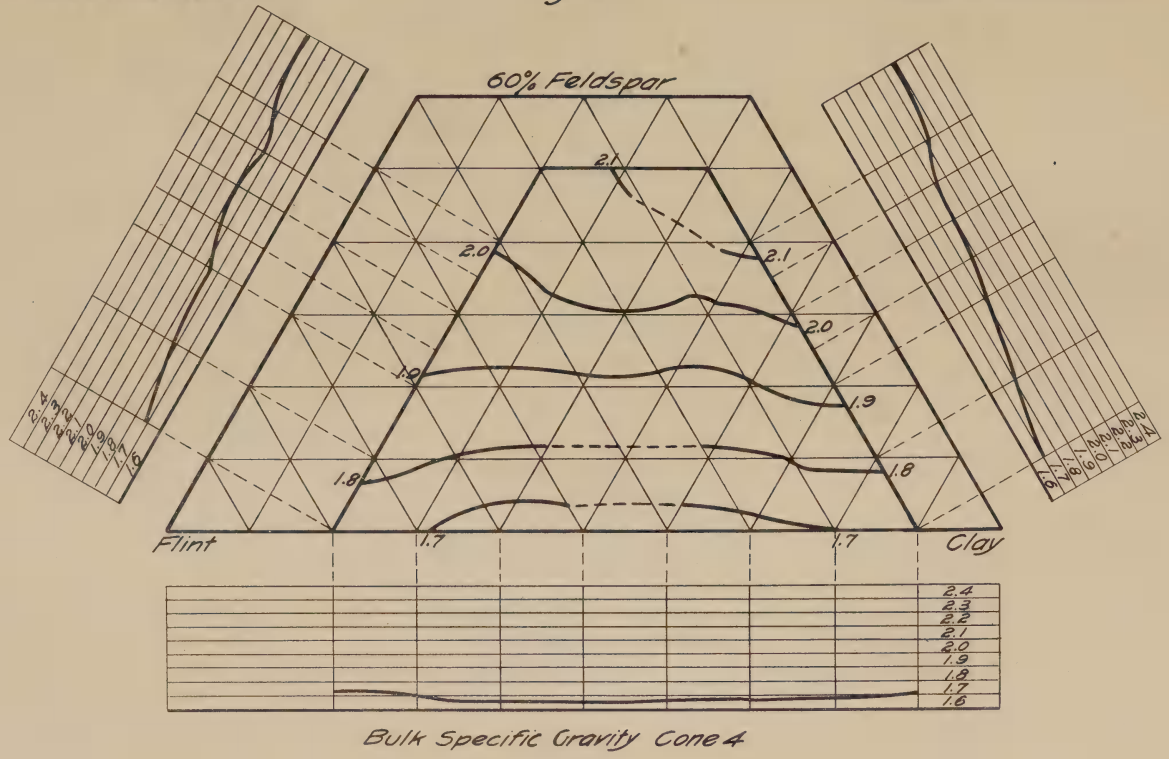
[1] In the triaxial diagrams here being discussed, and in those for true specific gravity and percent porosity, the small rectangles show the relative values for the bodies along the boundaries of the area studied. For each group of diagrams the datum lines of the rectangles represent the same values, so that by comparing one diagram with another in a given group the effect of heat treatment may be readily seen.

Trans. Am. Cer. Soc. Vol. XV Fig. 3. Potts & Knollman

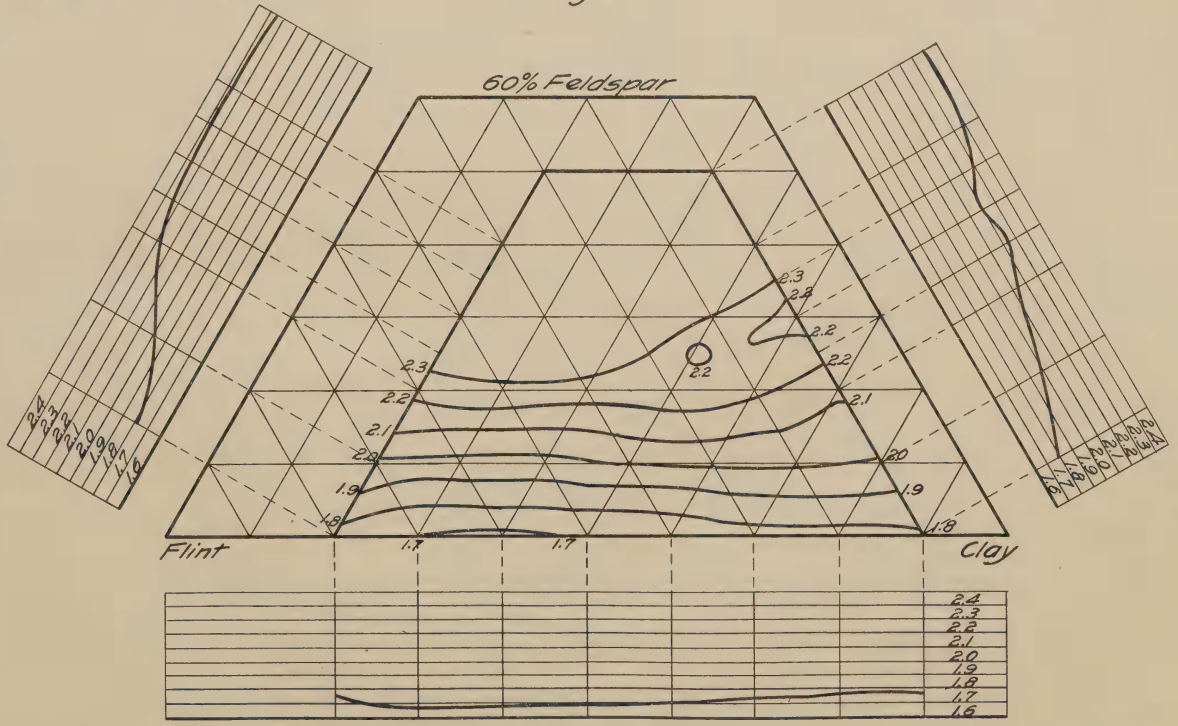


Bulk Specific Gravity Cone 2

Trans. Am. Cer. Soc. Vol. XV Fig. 4. Potts & Knollman



Trans. Am. Cer. Soc. Vol. XV Fig. 5. Potts & Knollman



Bulk Specific Gravity Cone 8

Trans. Am. Cer. Soc. Vol. XV Fig. 6. Potts & Knollman

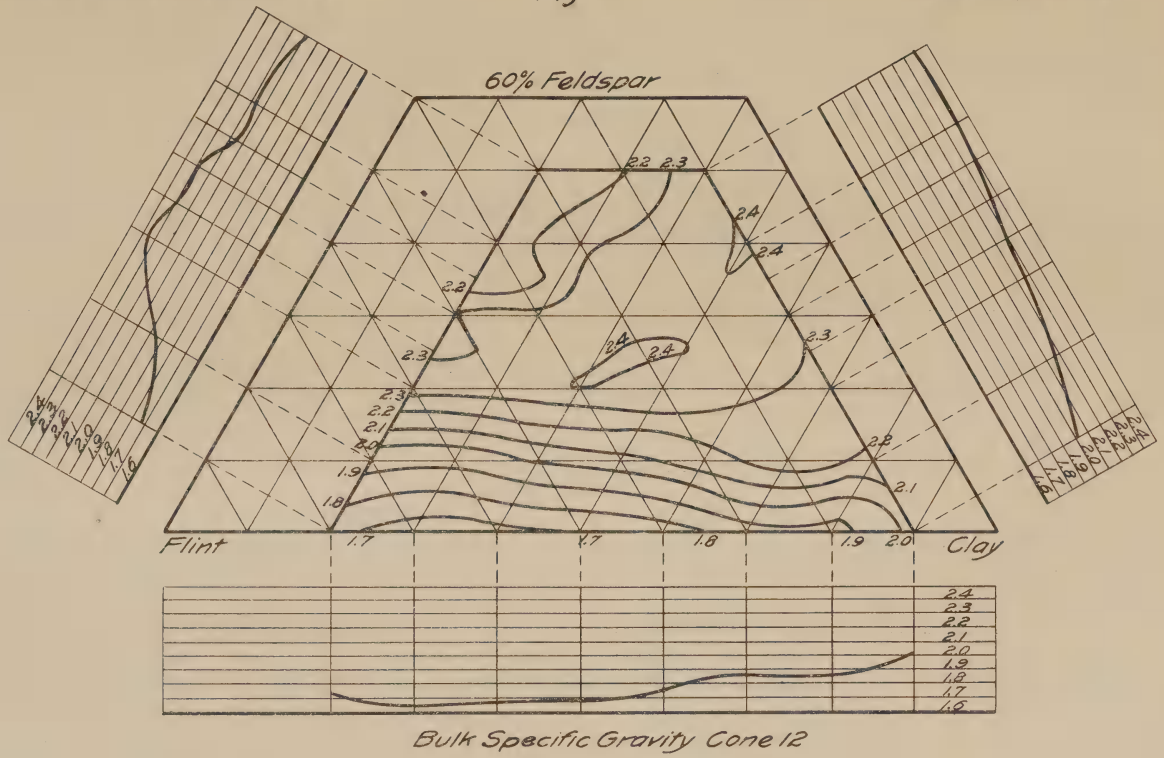


TABLE III—BULK SPECIFIC GRAVITY

BODY NO.	CONE 2	CONE 4	CONE 8	CONE 12
1	1.726	1.729	1.765	1.736
2	1.708	1.709	1.689	1.643
3	1.660	1.655	1.691	1.674
4	1.654	1.672	1.701	1.694
5	1.651	1.667	1.701	1.752
6	1.717	1.674	1.751	1.866
7	1.645	1.695	1.768	1.854
8	1.607	1.712	1.777	2.023
9	1.805	1.840	1.996	1.951
10	1.736	1.797	1.966	1.938
11	1.787	1.762	1.959	2.027
12	1.739		2.003	2.069
13	1.734	1.761	2.032	2.154
14	1.786	1.801	2.020	2.096
15	1.771	1.822	1.993	2.179
16	1.871	1.882	2.269	2.350
17	1.804	1.866	2.288	2.375
18	1.881	1.896	2.258	2.403
19	1.868	1.876	2.279	2.389
20	1.827	1.892	2.221	2.323
21	1.868	1.933	2.124	2.273
22	1.913	1.944	2.336	2.287
23	1.857	1.937	2.361	2.292
24	1.927	1.930	2.340	2.335
25	1.886	1.922	2.326	2.393
26	1.859	1.904	2.298	2.395
27	1.881	1.959	2.324	2.406
28	1.898		2.166	2.401
29	1.892		2.230	2.377
30	1.913		2.220	2.335
31	1.906		2.231	2.292
32	1.947	2.006	2.366	2.299
33	1.965		2.326	2.313
34	1.961	2.000	2.352	2.385
35	1.954	1.973	2.295	2.391
36	2.015	2.014	2.164	2.349
37	1.962	1.952	2.384	2.134
38	1.922	1.895	2.389	2.160
39	2.000	2.013	2.397	2.237
40	2.010	2.005	2.378	2.367
41	1.977	2.028	2.348	2.367

TABLE III—Continued

BODY NO.	CONE 2	CONE 4	CONE 8	CONE 12
42	2.043	2.024	2.369	2.399
43	2.130	2.051	2.354	2.400
44	2.062	2.048	2.299	2.387
45	1.941	2.019	2.391	2.152
46	2.123	2.002	2.361	2.270
47	2.078	2.066	2.372	2.371
48	2.110	2.144	2.357	2.405
49	2.073	2.096	2.362	2.092
50	1.993	2.132	2.393	2.171
51	2.142		2.399	2.394

If there were no change in the true specific gravity of the material, this data would represent the relative degree of vitrification; but it has been repeatedly shown, and in the data to follow it is shown again, that there is such a change in these materials with increased heat treatment. So, these curves do not show the true progress of vitrification.

Method of Study. The diagrams will first be studied by heat treatment and then as a group.

Cone 2. The interesting features of this diagram are: First, the evident uniformity in bulk density of bodies high in clay or flint when feldspar is low, 25 percent or less. This is shown by the curve at the bottom of the figure and also by the approximately straight course of the lines, connecting points of equal bulk specific gravity, across the diagram. Second, the rather more than expected increase in bulk density for the bodies higher in clay than flint when feldspar exceeds 25 percent of the total mix. This may also be seen by the trend of the curves on the triaxial diagram and by the position of the curves in the adjacent rectangles. It does not seem strange that these latter curves take the course that they do, but the question is how to account for the first observation. Ordinary reasoning would lead to the conclusion that of any two bricks with the same feldspar content, the one with the higher clay and hence the greater shrinkage should have the greater density. These observations would indicate that the bodies high in flint are given a much denser structure in the process of manufacture, which density is not equaled in the high clay bodies, even when

burned to cone 2. With bodies of higher feldspar content, the fluxing action of the latter together with change in density of the silica upon fusion, have combined to enable the high clay bodies to assume the greater bulk density shown.

Cone 4. At this heat treatment, the curves tell about the same story as those just discussed, except that all the values are a little more regular, and the bodies containing less than 25 percent feldspar are densest when clay and flint are present in nearly equal proportions.

Cone 8. These curves tell a very interesting story. Up to about ten percent of feldspar, the density remained practically constant regardless of the flint or clay content, but above this the bulk density of the high flint bodies increases more rapidly than does that of the high clay bodies. At about $22\frac{1}{2}$ percent of feldspar in the high flint bodies and 35 percent feldspar in the high clay bodies, we obtain approximately the same bulk density, and from this to the limit of the area investigated there is but little change. At this heat treatment we have apparently the largest area of uniformly densest bodies and the area includes more bodies of a composition high in flint than those high in clay.

Bodies 29 and 36 at this burn show unaccountably low bulk specific gravities; but it will be seen by consulting the data on true specific gravity that these bodies have given rather erratic data all the way through.

Cone 12. Here for the first time we have evidence of bloating due to high feldspar content and this defect is greater with the high flint bodies.

The line connecting the bodies of greatest bulk specific gravity begins with the composition 40 percent feldspar, 10 percent flint and 50 percent clay, then curves down slightly away from the line showing 50 percent clay content until it becomes tangent to the line showing a 20 percent feldspar content and passes beyond the area investigated. Below this line the bodies have apparently not yet attained their greatest density, while above this line the bulk specific gravity is decreasing due evidently to the formation of a bleb structure.

Here, as before, it is seen that the clay bodies represent a much more regular progress of vitrification than do those high in flint.

The evidence seems to indicate that a fusion of silica and feldspar is less viscous than is one of clay and feldspar, and flows in to fill or close the pores and then the entrained air, by expanding at the higher temperature, bloats the now softened brick. Undoubtedly, a portion of the decrease in bulk density is due to the fusion of silica, but a reference to our curves on porosity and true specific gravity, will show that this is not by any means the greatest factor.

Conclusion On Bulk Specific Gravity. These diagrams taken as a group show the following:—

1. Up to and including cone 8, an increase in feldspar means an increase in bulk specific gravity.

2. Between cones 8 and 12, the bodies high in feldspar develop a bleb structure which is most pronounced in the bodies highest in flint.

3. Bodies high in clay have a more regular and gradual process of vitrification than do bodies high in flint. This is in agreement with the practice of manufacturers of electric porcelain who use high clay and feldspar with low flint, to obtain the densest structure with the highest di-electric strength (see Watts, Vol. IV, *T. A. C. S.*, page 86).

TRUE SPECIFIC GRAVITY

Before making the determinations of the true specific gravities of the samples, the following references were consulted. On pages 47–49, Bull. 422 of the U. S. Geological Survey, are found two methods of determination. The ordinary method was to use a pycnometer with a capillary stopper, provided with a millimeter scale etched in the glass and calibrated so that the value of each division in weight of water was known. The capacity of the flask filled with water to the zero division was then calculated for every degree in temperature from 0° to 30° by making a series of careful weighings. For each pycnometer in use, a table was prepared showing its weight, the value of each scale division in grams of water and the capacity of the flask at different temperatures. The refined method uses a stopper slightly vaselined to prevent evaporation of water around the stopper. To obviate the error of incomplete removal of air from the powder, a slightly modified device, C. E. Moore's method (*American Journal of Science*, Series

3, Vol. 3, 1872) was used. The flask containing the powder was attached to a water pump with the intervention of a tube and bulb attachment. The bulb contained distilled water. When the system has been freed from air by the pump, water from the bulb is made to flow into the flask. The air is then removed by producing boiling within the flask. It is then filled and stoppered.

In Vol. 10, *T. A. C. S.*, Bleininger and Moore made some pycnometer determinations by weighing the powder in the pycnometer and filling them half full of water. The pycnometer was attached to a bent 50 cc. pipette containing water. The air was exhausted, and the pycnometer then filled by raising the pipette and allowing the air-free water to run into the apparatus.

In Blair's *Chemical Analysis of Iron*, a different kind of bottle, known as the Hogarth bottle, is used. It consists of a bottle with a long narrow neck into which fits a stopper with a small bulb at its upper end. "Its design is to avoid two difficulties experienced with the ordinary bottle, the expansion and overflow consequent upon transferring the flask at 60°F. to higher temperature of the balance case, and the necessity for waiting until the finely divided particles have settled before inserting the stopper. These difficulties were overcome by melting a capillary tubulus to the lower part of the neck of the flask and by grinding in a stopper having a small bulb above the capillary, to allow for expansion." The operation of determining the specific is gravity the same as the method to be described later.

Professor Purdy in Bulletin 9, Illinois Geological Survey, used the ordinary pycnometer or specific gravity bottles in his determinations. He used the method described below which, at his suggestion, was used in the present investigation. This method was deemed the most accurate and rapid for the time available.

Method of Determining True Specific Gravity. In making the true specific gravity determinations, the oridnary specific gravity bottle or pycnometer was used. It consists of a 50 cc. bottle, provided with a ground glass stopper having a small capillary tube.

Before making the determinations, a small piece of each briquette was broken up into small fragments with a hammer and then ground finely in a porcelain mortar with a porcelain pestle. The powder was ground fine enough as to to pass a 100-mesh

sieve, and was then stored in small bottles for future use. As some question arose as to whether the specific gravity of a body would not be affected by the wearing off of a little powder derived from the porcelain mortar, an experiment was made to see whether the specific gravity would be so affected. A small piece of a high feldspar body which had been burned to cone 12 and was very hard was weighed accurately, and then crushed and ground so as to pass a 100-mesh sieve, great care being taken not to lose any of the powder. This powder was again accurately weighed and found to weigh but a few milligrams more then the piece taken. By calculation it was found that the specific gravity would be affected only in the third decimal place, an entirely negligible factor.

In making the determinations, the dry, clean, and empty bottle was carefully weighed, the powder then introduced through a funnel, and the weight of the bottle and powder obtained. This eliminated any chance of losing some of the powder in transferring it to the bottle. The difference in weight gave the weight of the powder. Enough distilled water to completely cover the powder was then added and the bottle and its contents heated almost to the boiling point by placing it in a water bath. The bottle was then placed under a bell jar connected with an aspirator, and allowed to boil vigorously at the reduced pressure until all the air was expelled. A long glass U-tube containing mercury was attached to a measuring stick and connected to the tube between the bell jar and the pump. The mercury showed a difference in level of to 28 to 30 inches, so that a vacuum amounting to 28 to 30 inches of mercury was always present.

After boiling had ceased, the aspirator was shut off, the air allowed to enter and the bottles removed from the bell jar. The bottles were filled carefully with boiled distilled water almost to the top of the tube, and the stopper then inserted very carefully, so as to exclude any air bubbles. The bottles were filled so that a little of the liquid would come out through the capillary tube in the stopper. The bottle was then immediately immersed in a vessel containing boiled distilled water, heated to about 35°C. The bottles were then allowed to cool from about 35°C. to exactly 30°C., requiring about one and a half hours, thus giving sufficient time to have the temperature of the contents inside the bottle the same

as the water in which they were immersed. When the temperature was exactly 30°C., the bottles were taken out and the excess water on top of the stopper quickly wiped off so that the exact volume at 30°C. was obtained. The flask was then dried, allowed to stand a little while in order to acquire the temperature of the balance case and then carefully weighed.

The weight of the bottle, water and powder is designated as W'. The weight of the bottle filled with water at 30°C. was obtained in exactly the same way as described above. The weight of the bottle and water at 30°C. is designated as K, while the weight of the powder is designated as W. True specific gravity was then calculated from the formula:

$$\text{Specific gravity} = \frac{W}{W + K - W'}$$

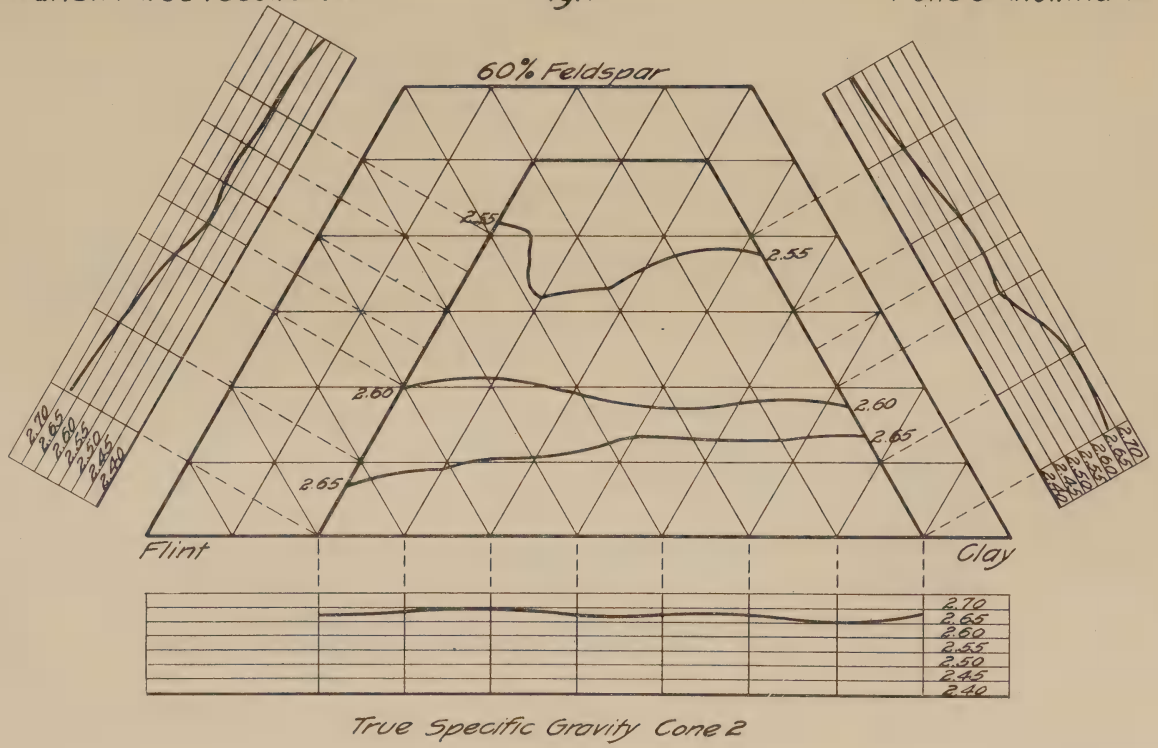
Two check determinations for each body were made, and the two determinations had to check within 0.04, or another check determination was made. Considerable difficulty was experienced in getting check determinations until the method was obtained for getting an accurate control of the temperature at which the volumes were adjusted. In the data obtained there are about three dozen bodies in which the check determinations do not agree within .02 in the specific gravities, but owing to the lack of time these were not redetermined. All check determinations are within .04 in the specific gravity values.

True Specific Gravity Curves. The results of the true specific gravity determinations are shown in Table IV. In order to study the effect of composition on true specific gravity, the results are assembled, as in the case of the bulk specific gravities, on triaxial diagrams, Figs. 7, 8, 9 and 10.

Cone 2. In this diagram, we find a very slight difference in the true specific gravity of the high clay bodies, as compared to those high in flint, but the increase of feldspar has in all cases tended to materially decrease the true specific gravity of the bodies. This phenomenon is seen to begin later and take place a little more rapidly in the high clay than in the high flint bodies.

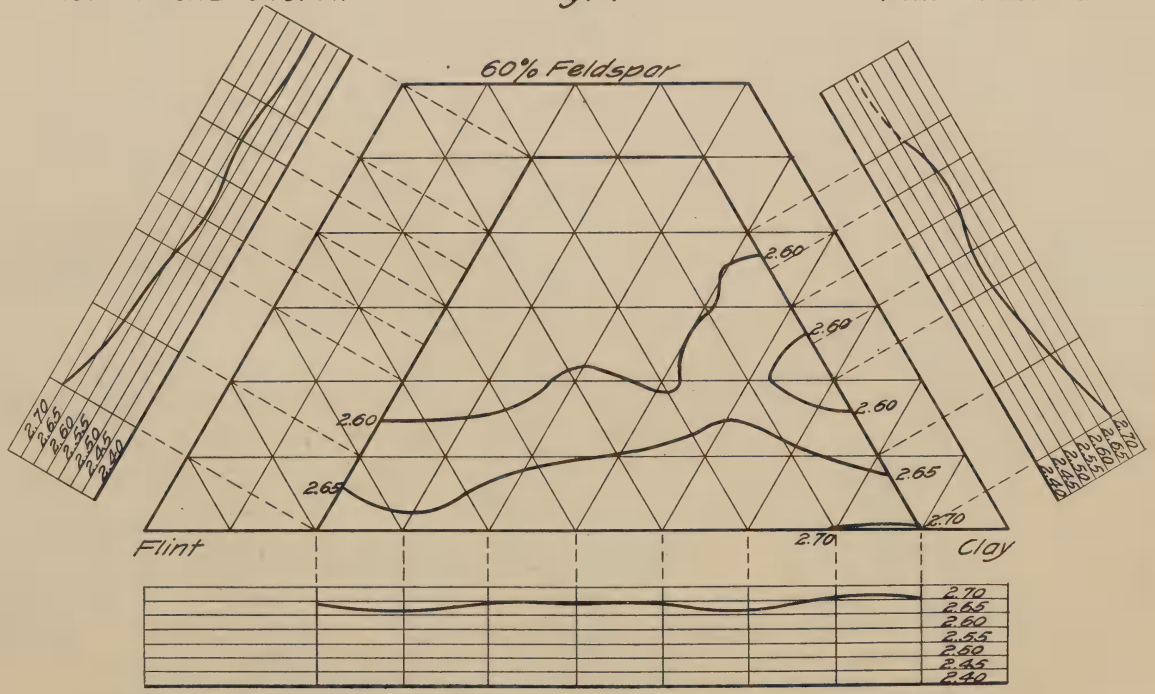
Cone 4. Here we find that the curves are considerably more irregular. The clay and feldspar bodies have as a rule increased in true

Trans. Am. Cer. Soc. Vol. XV Fig. 7 Potts & Knollman



True Specific Gravity Cone 2

Trans. Am. Cer. Soc. Vol. XV Fig. 8. Potts & Knollman

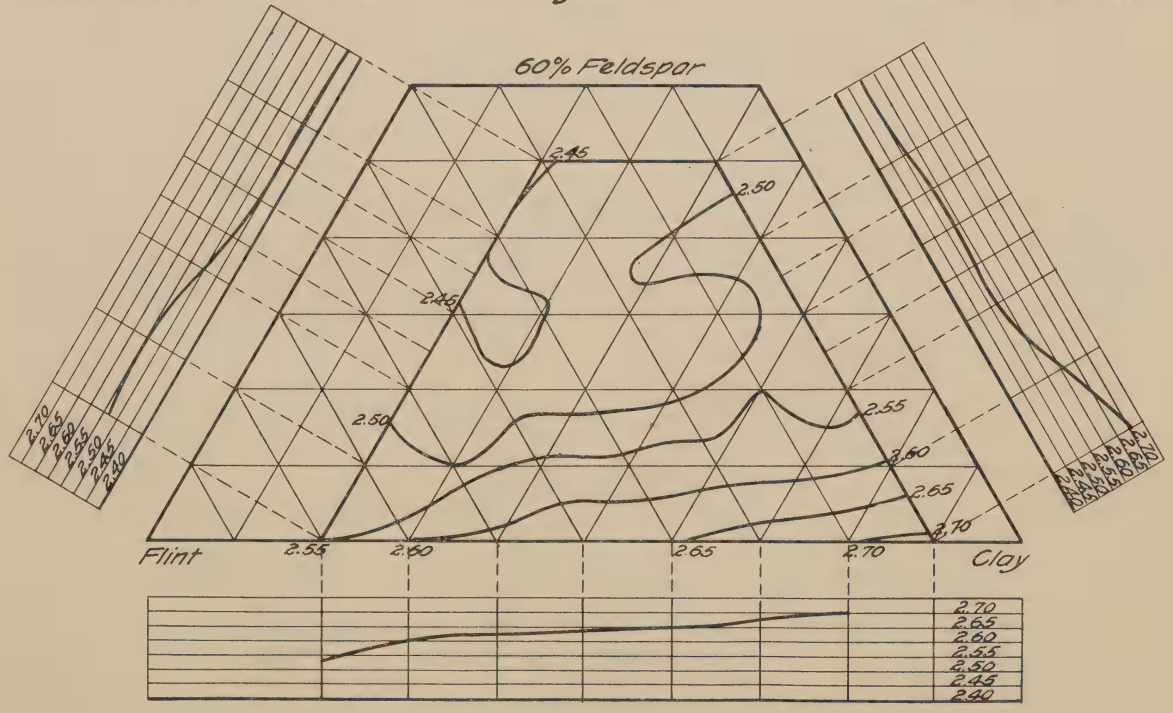


True Specific Gravity Cone 4

Trans. Am. Cer. Soc. Vol. XV Fig. 9. Potts & Knollman

True Specific Gravity Cone 8

Trans. Am. Cer. Soc. Vol. XV Fig. 10 Potts & Knollman



True Specific Gravity Cone 12

TABLE IV.—TRUE SPECIFIC GRAVITY

BODY NO.	CONE 2	CONE 4	CONE 8	CONE 12
1	2.674	2.688	2.624	2.532
2	2.688	2.662	2.640	2.607
3	2.698	2.697	2.605	2.616
4	2.676	2.692	2.736	2.640
5	2.672	2.691	2.668	2.640
6	2.670	2.665	2.704	2.672
7	2.652	2.709	2.704	2.697
8	2.674	2.709	2.726	2.710
9	2.642	2.620	2.570	2.542
10	2.648	2.618	2.564	2.495
11	2.652	2.647	2.585	2.560
12	2.696		2.621	2.564
13	2.678	2.675	2.601	2.678
14	2.682	2.663	2.660	2.580
15	2.699	2.638	2.578	2.611
16	2.601	2.583	2.519	2.498
17	2.614	2.588	2.522	2.467
18	2.597	2.608	2.532	2.479
19	2.578	2.596	2.556	2.515
20	2.587	2.610	2.548	2.554
21	2.579	2.570	2.568	2.526
22	2.587	2.566	2.507	2.464
23	2.539	2.565	2.508	2.455
24	2.569	2.580	2.512	2.439
25	2.575	2.582	2.520	2.497
26	2.553	2.589	2.522	2.494
27	2.590	2.601	2.548	2.487
28	2.603		2.579	2.485
29	2.505		2.579	2.498
30	2.585		2.540	2.514
31	2.617		2.575	2.528
32	2.580	2.571	2.503	2.453
33	2.573		2.505	2.445
34	2.589	2.562	2.522	2.490
35	2.567	2.599	2.531	2.467
36	2.593	2.613	2.567	2.532
37	2.568	2.580	2.477	2.443
38	2.565	2.575	2.495	2.455
39	2.527	2.591	2.518	2.461
40	2.536	2.590	2.501	2.496
41	2.574	2.552	2.533	2.505

TABLE IV—Continued

BODY NO.	CONE 2	CONE 4	CONE 8	CONE 12
42	2.571	2.585	2.509	2.500
43	2.578	2.610	2.477	2.509
44	2 562	2.617	2.543	2.528
45	2.561	2.567	2.479	2.453
46	2.548	2.591	2.509	2.538
47	2.504	2.582	2.497	2.502
48	2.542	2.556	5.527	2.512
49	2.523	2.560	2.473	2.446
50	2.525	2.559	2.493	2.462
51	2.511		2.481	2.494

specific gravity at this heat treatment, while the flint bodies have decreased. There is again a decided decrease in either case with the addition of feldspar, which is again more regular and gradual in the high flint bodies. The decrease in specific gravity of the high flint bodies may be accounted for by the inversion of quartz to tridymite or chrystobalite or by fusion in feldspar (see Purdy and Moore, Vol. IX., *T. A. C. S.*, page 226). The increase of specific gravity of the clay bodies may be of the same nature as the phenomena observed by Ogan (Vol. XII, *T. A. C. S.*, page 609) when working with fire clay; but how account for the higher true specific gravity of the feldspar bodies at cone 4 as compared with cone 2?

Cone 8. Here again there is a slight increase in true specific gravity in the bodies highest in clay and lowest in feldspar; but aside from this, there is a general decrease over the whole area investigated.

Cone 12. Here the general decrease in true specific gravity noted in the cone 8 data is even more pronounced; but at the same time it should be noted that the body highest in clay has changed very slightly if any.

In review, this group of curves seems to show that clay substance, whether derived from a mixture of china and ball clays or from fire clays, as shown by Ogan (loc. cit.), increases in true specific gravity, while silica added as flint and feldspar decreases, as has been repeatedly shown by other investigators. The question unanswered is, how account for the increase in specific gravity of feldspar at cone 4?

POROSITY DATA

How Obtained. Because of the difficulty of obtaining complete saturation, no attempt was made to differentiate between open and sealed pores. The data here given represents total pore space on the basis of the exterior of volume of the burned brickette.

This data is most simply obtained from the bulk and true specific gravity by means of a formula developed by Prof. R. C. Purdy, which is as follows:

$$100\left\{1 - \frac{B.Sp.G.}{T.Sp.G.}\right\} = \text{Percent porosity}$$

and is derived as follows:

$$\frac{D}{B.Sp.G.} = \text{Exterior volume.}$$

$$\frac{D}{T.Sp.G.} = \text{Volume of solid material.}$$

$$\frac{D}{T.Sp.G.} \div \frac{D}{B.Sp.G.} = \frac{D}{T.Sp.G.} \times \frac{B.Sp.G.}{D} = \frac{B.Sp.G.}{T.Sp.G.} = \left\{\begin{array}{l}\text{Ratio of}\\ \text{solid to}\\ \text{exterior}\\ \text{volume.}\end{array}\right.$$

This multiplied by 100 = percent of solid.

$$100 - \text{percent solid} = \text{percent total pores.}$$

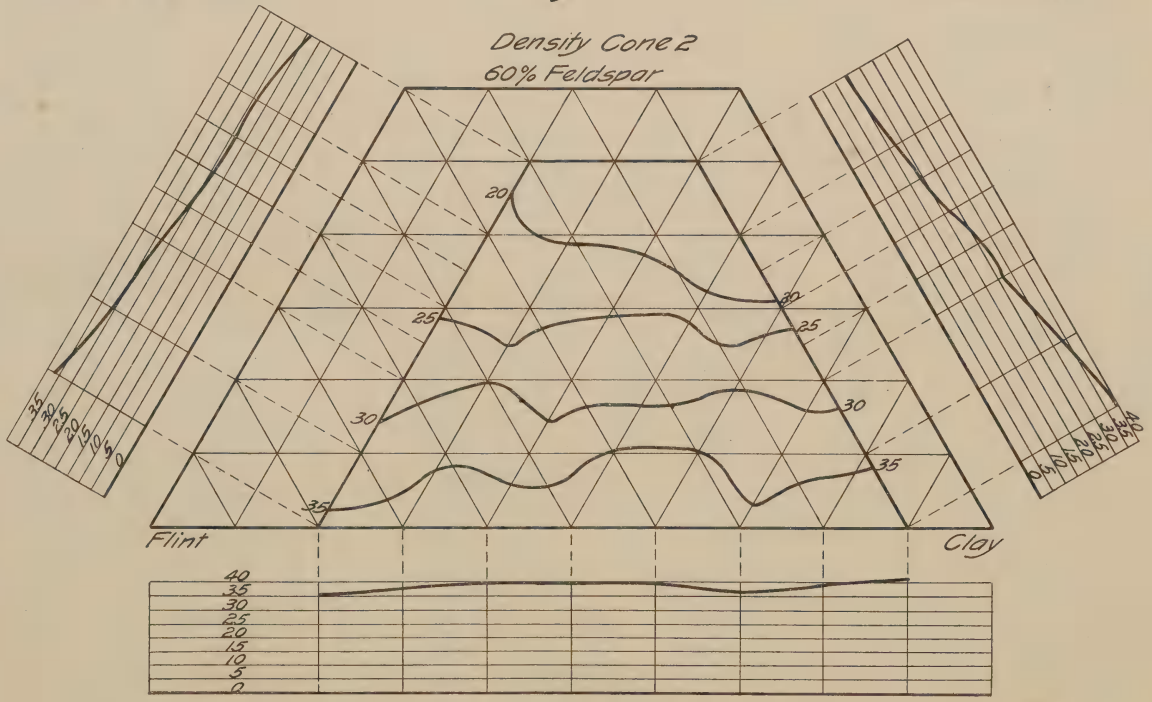
or

$$100 - 100\,\frac{B.Sp.G.}{T.Sp.G.} = 100\left(1 - \frac{B.Sp.G.}{T.Sp.G.}\right) = \text{percent total pores.}$$

The data so obtained will be found in the tabulated data sheet Table V and is also plotted, as in the case of the true specific gravity data, on triaxial diagrams (see Figs. 11, 12, 13 and 14).

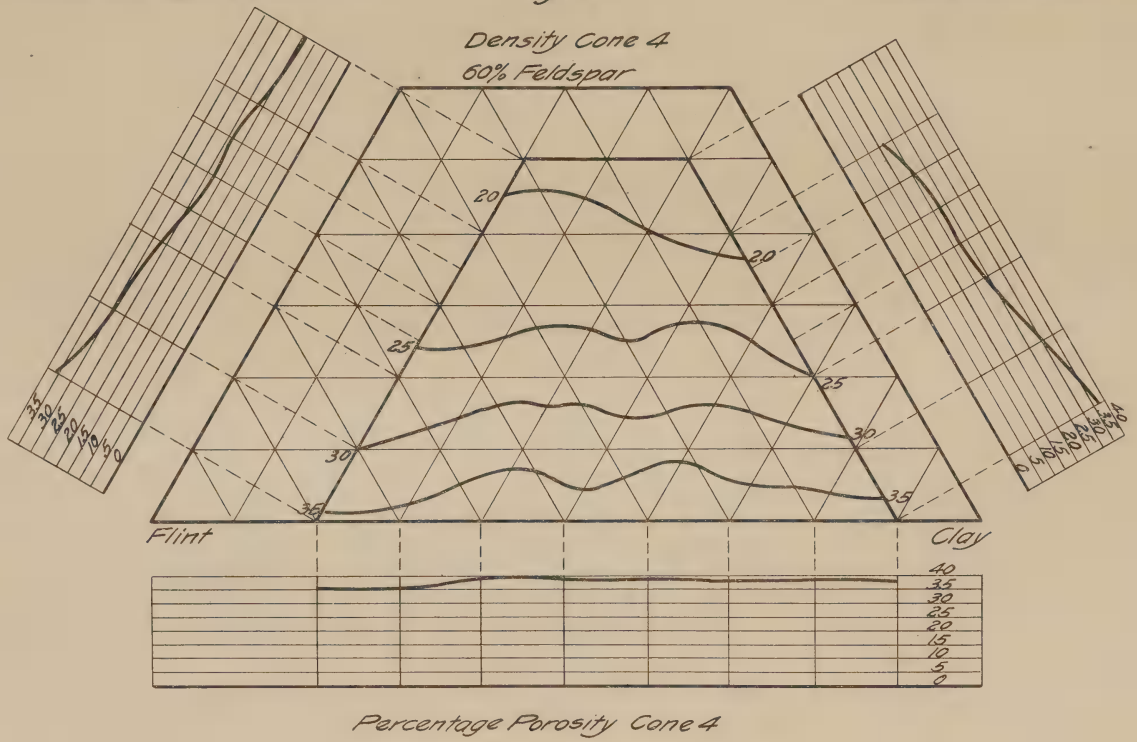
Cone 2. We find here that the bodies higher in flint and containing no feldspar have slightly less pore space than do those higher in clay, which is in accord with Seger, page 675. With increase of feldspar content the high clay bodies decrease much more rapidly than do those high in flint until at 35 percent feldspar the clay bodies have as low a percentage pore space as have the bodies containing 50 percent feldspar and 30 percent flint.

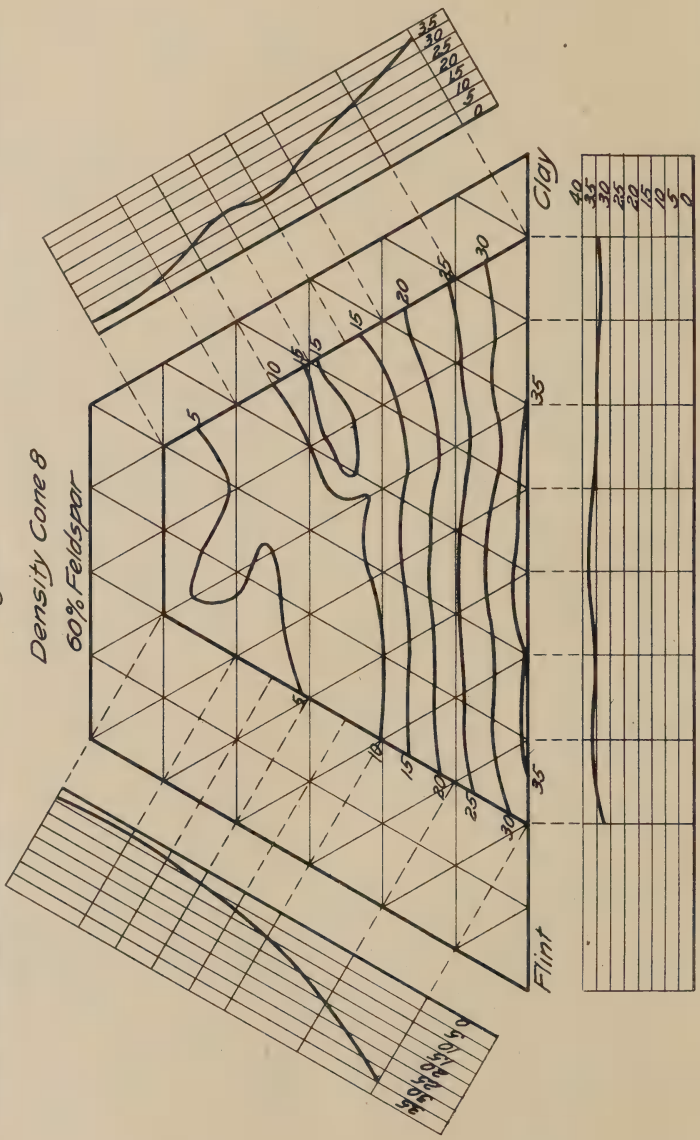
Trans. Am. Cer. Soc. Vol. XV Fig. 11. Potts & Knollman



Percentage Porosity Cone 2

Trans. Am. Cer. Soc. Vol. XV Fig. 12. Potts & Knollman




Trans. Am. Cer. Soc. Vol. XV
Fig. 13.
Potts & Knollman
Density Cone 8
60% Feldspar
Clay
Flint
Percentage Porosity Cone 8

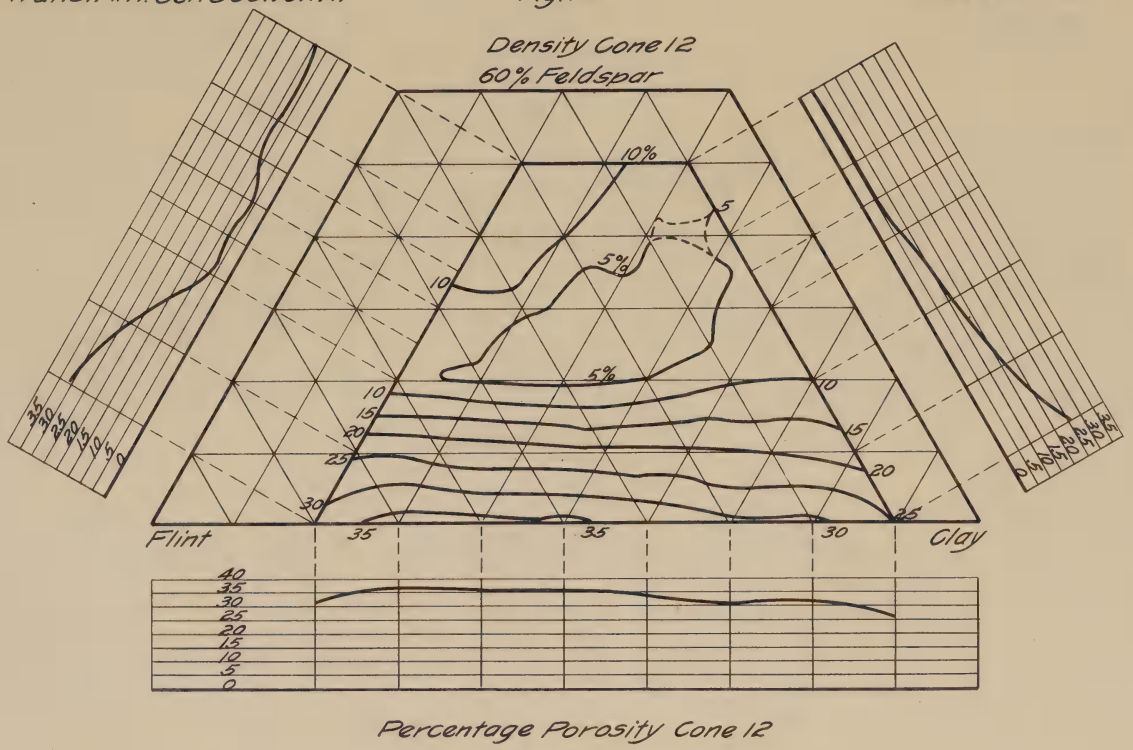

Trans. Am. Cer. Soc. Vol. XV
Fig. 14.
Potts & Knollman
Density Cone 12
60% Feldspar
10%
5
5%
5%
10
15
20
25
30
35
Flint
Clay
Percentage Porosity Cone 12

TABLE V—PERCENT POROSITY ON BASIS OF EXTERIOR VOLUME

BODY NO.	CONE 2	CONE 4	CONE 8	CONE 12
1	35.5	35.7	32.7	31.4
2	36.4	35.8	36.0	37.0
3	38.4	38.4	35.1	35.9
4	38.2	37.9	37.7	35.8
5	38.2	38.1	36.2	33.6
6	35.7	37.2	35.2	30.2
7	37.9	37.4	34.6	31.1
8	39.9	36.8	34.8	25.3
9	31.8	29.7	22.3	23.1
10	34.4	31.4	23.2	22.3
11	32.2	33.2	24.2	20.8
12	35.5		23.6	19.3
13	35.3	34.2	21.9	19.5
14	33.4	32.4	24.0	18.6
15	34.4	31.0	25.5	16.6
16	28.1	27.2	9.9	5.9
17	31.0	25.1	9.1	4.1
18	27.6	27.3	10.8	3.0
19	27.6	27.7	10.9	5.0
20	29.3	27.6	12.8	9.0
21	27.6	24.2	17.1	10.0
22	26.0	24.2	6.9	7.2
23	26.8	24.5	5.8	6.6
24	24.9	25.2	6.9	4.3
25	26.7	25.6	7.6	4.1
26	27.2	26.5	9.0	4.0
27	27.4	34.7	8.6	3.2
28	27.1		15.9	3.4
29	24.5		13.2	4.8
30	26.0		12.6	7.0
31	27.1		13.2	9.2
32	24.5	22.0	5.3	6.3
33	23.7		7.0	5.3
34	24.2	21.9	6.8	4.2
35	23.8	24.0	9.4	4.0
36	22.7	23.0	15.7	7.2
37	22.5	24.3	3.6	12.7
38	25.1	26.4	4.3	12.0
39	20.8	22.3	4.7	9.1
40	20.7	22.6	4.9	5.2
41	23.2	20.5	7.2	5.6

TABLE V—Continued

BODY NO.	CONE 2	CONE 4	CONE 8	CONE 12
42	21.2	21.7	5.5	4.0
43	17.3	21.3	5.0	4.3
44	19.4	21.7	9.7	5.6
45	24.2	21.3	3.5	12.2
46	16.6	22.7	5.8	9.6
47	17.0	20.0	5.1	5.2
48	17.0	16.1	6.9	4.3
49	17.8	18.0	4.4	14.4
50	21.0	16.6	4.0	11.8
51	14.6		3.4	4.0

Cone 4. At this heat treatment, the curves are a little more regular in their trend across the diagram, but again the flint bodies have rather less porosity than the clay bodies when the feldspar is low. The porosity decreases less rapidly with increase of feldspar in the case of high flint than of high clay; but it is also evident that the bodies of nearly equal flint and clay contents have greater porosity than when either of these materials predominate. They lose this porosity at least as rapidly as in the case of high clay.

Cone 8. At this heat treatment, we have a different set of conditions. The flint and clay bodies with no feldspar have about the same porosity, with a very slight max point at flint 50 clay 50. With increase of feldspar to 40 percent the porosity of the high flint bodies decreased quite rapidly, beyond which there is a slight increase, probably due to the beginning of the formation of a bleb structure, while on the clay side of the diagram there is a continuous and very gradual decrease in porosity, with the exception of a small area containing bodies 29 and 36, which have already been noted as being erratic.

Cone 12. Here we find the body containing 80 percent flint and 20 percent clay with a higher porosity than has the body containing 80 percent clay and 20 percent flint. We find, for the first time, a well defined area of increased porosity due to the formation of a vesicular structure (with high feldspar content); and it is interesting to note that this area falls in about the same place as was indicated by the bulk specific gravity data. The area of greatest density, 5 percent or less pore space, is now included almost wholly

within the limits 20 to 40 percent feldspar and 30 to 55 percent clay; and the densest body found in this study, containing 3.2 percent pore space, has the composition 25 percent feldspar, 45 percent clay and 30 percent flint.

In summing up, it may be said that taken as a group these curves indicate that bodies high in flint vitrify much more rapidly and erratically than do those of equal feldspar content but high in clay. Coincident with this more rapid vitrification, the flint bodies are much more liable to the formation of a vesicular structure.

DISCUSSION

Mr. Bleininger: I would like to bring out a point in this connection and would like to ask Mr. Potts whether in his opinion it would not be better to use, as the basis of the body changes, the true volume of the clay itself? I simply ask this question for the sake of uniformity, because I am quite sure that work of a similar nature is bound to be carried on and it might be advisable to express the results on the same basis.

Prof. Potts: I don't know whether I understand the Professor's question.

Mr. Bleininger: In plotting the pore volumes, you would have a diagram in which the true clay volume is always 100.

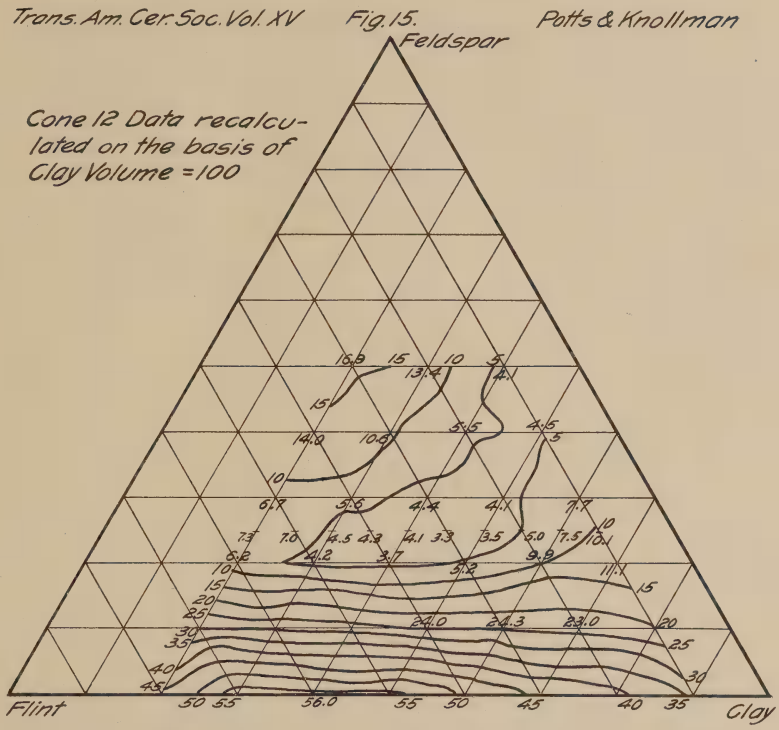
Mr. Purdy: Do you mean to figure in the porosity?

Mr. Bleininger: Yes, expressing the pore volume in terms of the true clay volume.

Prof. Potts: The proposition, then, is instead of working it back to a unit volume of the brick on the basis of bulk specific gravity, to take the unit volume of the clay substance. That could have been done as easily, but I doubt whether the formula would have been as simple as this one. We already have the bulk specific gravity data and the true specific gravity data and it was a simple matter to use that formula and get the brick of unit weight.

NOTE WRITTEN AFTER READING THE DISCUSSION

Prof. Potts: In response to the sentiment expressed by Mr. Bleininger the porosities of the brickettes have been recalculated on the basis of the clay volume; see Table VI. Contrary to the



statement of the writer, the formula for calculation on this basis is just as simple as the one used in the paper and is derived as follows:

$$\frac{W}{BSG} = \text{exterior volume}$$

$$\frac{W}{TSG} = \text{clay volume}$$

then

$$\frac{W}{BSG} - \frac{W}{TSG} = \text{volume of pores.}$$

and

$$\frac{W\left(\frac{1}{BSG} - \frac{1}{TSG}\right)}{W\left(\frac{1}{TSG}\right)} \times 100 = \text{percent pores on the basis of clay volume.}$$

TABLE VI—PERCENT POROSITY ON BASIS OF CLAY VOLUME

BODY NO.	CONE 2	CONE 4	CONE 8	CONE 12
1	55.0	55.5	48.5	45.8
2	57.3	55.7	56.2	58.7
3	62.5	63.0	54.0	56.0
4	61.8	61.1	60.6	55.8
5	61.8	61.5	56.8	50.6
6	55.5	59.2	54.3	43.2
7	61.1	59.7	52.9	45.1
8	66.5	58.2	53.3	33.9
9	46.5	42.3	28.7	30.0
10	52.5	45.7	30.2	28.7
11	47.3	49.2	32.0	26.4
12	55.0		30.9	24.0
13	54.5	52.0	28.0	24.3
14	50.2	47.9	31.6	23.0
15	52.4	44.8	34.2	20.0
16	39.0	37.3	11.0	6.2
17	45.0	33.6	10.0	4.2
18	38.0	37.5	12.1	3.1
19	38.0	38.2	12.3	5.2
20	41.5	38.0	14.7	9.9
21	38.0	32.0	20.7	11.1
22	35.1	32.0	7.4	7.3
23	36.7	32.5	6.1	7.0
24	33.2	33.7	7.4	4.5
25	36.5	34.4	8.2	4.3
26	37.4	36.0	9.9	4.1
27	37.7	32.8	9.4	3.3
28	37.1		18.9	3.5
29	32.5		15.3	5.0
30	35.1		14.5	7.5
31	37.1		15.3	10.1
32	32.5	28.2	5.6	6.7
33	31.0		7.5	5.6
34	32.0	28.1	7.3	4.4
35	31.3	31.6	10.4	4.1
36	28.7	29.8	18.7	7.7
37	29.0	32.1	3.7	14.6
38	33.5	35.8	4.5	13.6
39	26.3	28.7	4.9	10.0
40	26.1	29.2	5.1	5.5
41	30.2	25.9	7.7	5.9

TABLE VI—Continued

BODY NO.	CONE 2	CONE 4	CONE 8	CONE 12
42	27.0	27.7	5.8	4.1
43	21.0	27.2	5.2	4.5
44	24.2	27.7	10.7	5.9
45	31.9	27.1	3.6	14.0
46	20.0	29.4	6.1	10.6
47	20.5	25.0	5.4	5.5
48	20.5	19.2	7.4	4.5
49	21.7	22.1	4.6	16.9
50	26.7	20.0	4.1	13.4
51	17.1		3.5	4.1

This simplifies as follows, after canceling the W's,

$$100\left(\frac{1}{BSG}-\frac{1}{TSG}\right)\times\frac{TSG}{1}=$$

$$100\times\frac{TSG-BSG}{BSG\times TSG}\times\frac{TSG}{1}=\frac{TSG-BSG}{BSG}\times 100$$

which is

$$\left(\frac{TSG}{BSG}-1\right)\times 100 = \text{percent porosity.}$$

In the above W = Weight
BSG = Bulk specific gravity
TSG = True specific gravity

There is some advantage in this method. While it gives a much higher number to express the percent porosity of the very porous brickettes, i.e., a brick having 50 percent pores on the basis of exterior volume will have 100 percent pores on the basis of the clay volume, it does not materially change the figures for the very dense brickettes, for instance, a brickette showing 3 percent porosity on the basis of exterior volume shows only 3.1 percent porosity on the basis of clay volume. Therefore, the change in porosity with heat treatment or composition is relatively magnified and the area of densest structure more sharply defined.

THE MINERALOGICAL EXAMINATION OF CLAYS

BY WILLIAM J. MCCAUGHEY

The petrographic microscope has been of invaluable assistance to the geologist in the study of rocks. By the use of thin sections, he has been able to study the details of texture and structure and the mineralogical composition of the rocks. This information has been of assistance in determining the origin of rocks and the forces which have been active in their formation or subsequent modification. The application of these methods to unconsolidated material, as sand and clays, has been of much slower development. This fact has been due, partly, to the difficulties in preparing sections of such materials.

It is obvious that the study of the structure of unconsolidated deposits is not as important as in the case of the hard rocks. Therefore, the textural study is confined to the physical or mechanical analyses of such deposits, which expresses the composition only as to the size of the particles. The coarser particles are separated on appropriately sized sieves, and the finer grains by water or air elutriation, aided in some cases by use of a centrifuge.

The earlier microscopic studies of such unconsolidated deposits were patterned after the manner of microscopic rock study. The particles were united into a plaque by the use of a zinc oxide cement and a thin section prepared in the usual manner. Such sections are difficult to prepare and unsatisfactory where the particles are quite small in size.

J. W. Retgers, in his chemical and mineralogical study of the dune sands of Holland, contributed the first important study of such material. This work was continued by Schroeder Van der Kolk, who developed in his study of these Holland deposits, methods particularly suited to such material. More recent developments in the use of the petrographic microscope have made possible the examination and the measurement of the optical constants of crystals and minerals in fine powder. It is now possible to determine a few of these constants when the mineral grain has a diameter of 0.01 mm. If its constants are measurable, the mineral can be identified by the use of mineral tables. Here it is well to make the

point and emphasize it, that though particles of a size 0.005 mm. lend themselves at times to these methods, the mineral grains should be preferably 0.01 mm. in diameter or greater.

This method of examination has been applied to soils as a substitute for chemical analysis. Its advantage is twofold. It affords a cheap and rapid method for the determination of the approximate chemical composition of the soil. Its other advantage lies in the disclosing of the nature of the minerals that make up the soil. Chemical analysis shows how much of certain elements are present, but does not indicate in what form they are present. There is reason for believing that minerals having similar composition react differently, have a different solubility in water; and this is borne out by observation in many samples of soil. There is also *a priori* reason for believing that some of these minerals will react differently at high temperatures since these minerals possess different softening and melting points. It would, therefore, seem that the mineral composition of a clay will be of importance in determining some of its properties.

The method for the identification of minerals demands the determination of the following:

a. Indices of refraction
b. Isotropic-Uniaxial-Biaxial
c. Birefringence
d. Character of birefringence + or −
e. Extinction angle from cleavage direction
f. Character of elongation.

The optical constants *a* and *c* may be quantitatively determined. Their value will vary within limits, according to the direction in which the light passes through the mineral grain. The other constants are qualitative. In cases where larger grains are obtainable, as in the sands, the accuracy of measurement of these constants are of much higher grade. See in this case Wright, Pub. No. 158, Carnegie Institution.

Index of Refraction. The velocity of light transmission varies in different minerals. The velocity of light in two minerals is inversely proportional to their indices of refraction, an optical constant which is readily measured under the miscroscope. The index of refraction is constant for each mineral (varying slightly with

difference in composition) and is the most valuable means of distinguishing minerals in fine powder.

In minerals crystallizing in the isometric system, garnet, fluorite, spinel and in glasses not under strain, this value is independent of the direction in which the light passes through the crystal. For instance, the index of refraction of fluorite will be 1.434, no matter in what direction the light passes through the mineral. In minerals crystallizing in other systems than the isometric, the value of the indices will vary according to the direction in which the light passes through. Light passing through such minerals will be split up into two sets of light waves, whose vibrations will be at right angles to each other. These two sets of light waves will have different velocities in the crystal, and, therefore, the mineral will have two indices of refraction for each direction of light transmission. It is possible to intercept either set of these vibrations and to measure the index of the mineral in each of these two vibration directions. When such a mineral is viewed in polarized light between crossed nicols, the vibration directions are parallel to those of the nicols when the mineral is at the position of extinction. If the analyzing nicol is now removed, only one set of light waves of the crystal is transmitted; therefore, the index of the mineral may be determined in this direction.

The difference in the value of these indices will vary according to the direction in which the light passes through the mineral. This difference in indices of these two vibration directions is known as birefringence and is a property of minerals crystallizing in systems other than the isometric. Birefringence is manifested by transmitting light between crossed nicols. The interference color produced is dependent both on the thickness of the mineral grain and on the birefringence.

In general, the change in index of refraction due to difference in the direction of light transmission is moderately small, occurring within certain narrow limits (excepting a few minerals as calcite, zircon, rutile). The regular change in indices of refraction with change in the direction of light transmission is readily explained by the use of Fletcher's Indicatrix (see Dana, *Text-book of Mineralogy* or Idding's *Rock Minerals*).

Birefringence is determined by measuring the thickness of the

mineral grain and matching the color on Michel Levy's Birefringence plat. Birefringence is not a constant value but varies with the direction of light transmission.

The direction of light transmission in a crystal can be recognized by certain interference phenomena seen in convergent polarized light. These interference figures also indicate whether an anisotropic mineral is uniaxial or biaxial, and by using appropriately prepared plates of quartz, determines whether the mineral is + or −. The details of reactions may be seen in Johannsen's *Key to the Rock Forming Minerals.*

If a mineral grain is rotated between crossed nicols, the light transmitted through the mineral drops off to darkness four times in a revolution of 360°. When the mineral grain is at the position of extinction, the vibration direction of the two light waves in the mineral are coincident with the vibration planes of the nicols, and these latter are indicated by the cross hairs in the eyepiece of the microscope. The angle included between the position of extinction and a position in which a definite crystallographic direction is parallel to the cross hairs, is known as the angle of extinction and is important in determining minerals. Generally the crystallographic direction is the trace of a cleavage, as is the case with the feldspar. The angle of extinction is particularly serviceable in distinguishing minerals with prismatic elongation. If the elongation of such a mineral is parallel to the cross hairs when at the position of extinction the mineral is said to have parallel extinction, otherwise its extinction is oblique. If the vibration direction of the slow ray, that is, the direction with the greater index, is parallel or nearly parallel to the cross hairs, the mineral is said to have positive elongation; if the direction is that of the fast ray or the direction with low index, the mineral has negative elongation.

Methods for the recognition of uniaxial and biaxial minerals and for the determination of the character of birefringence (positive or negative) is taken up in Bulletin 91 of the U. S. Bureau of Soils, to which those interested may be referred for fuller discussion. The application of these methods for the identification of minerals occurring in soils and clays requires skill and dexterity in handling these fine particles under the microscope.

A preliminary preparation is necessary to clean the surfaces of the

particles and disintegrate any aggregates, otherwise these particles will not be transparent. A five gram sample is placed in a bottle with about 30 cc. of water to which a few drops of ammonia are added. This mixture is violently shaken and allowed to settle. The shaking scours the surface of the grains, the ammonia serves to deflocculate the colloidal clay particles and keep them in suspension. The sample is repeatedly washed in order to separate the silt and clay from the sand grains, since these are examined separately. The separates are then dried in an evaporating dish. Feldspar particles found in some clays weather, forming more or less porous grains. These crevices become filled with infiltrated iron oxide or clay, which is not removed by the method above. A cold dilute hydrochloric acid solution (1 to 10) may remove this iron oxide. Sand grains of a size greater than 0.5 mm. should be broken in a mortar until they pass a hundred mesh sieve and then washed as above.

To prepare a section for examination, take a sample of the dried material (3 or 4 mgms.) and place on an object slide, then add a drop of oil. These two are incorporated and a cover glass placed on top. The oil covers up irregularities in the surface thereby permitting light to pass through the mineral. By using oils of different refractive indices, it is easy to measure the indices of the mineral (see paper on "Examination of Commercial Spar"). The silt particles dry down to a cake; this must be broken up in a mortar and passed through a hundred mesh sieve to disintegrate and separate the particles.

The minerals composing the silts are at times altered and weathered to such an extent that they are more or less porous. Kaolin-like material and iron oxide are infiltrated into this porous grain and render the mineral opaque. At times the grains are coated with a thin coating of iron oxide, which does not interfere with their transparency but produces anomalous optical reactions, particularly interfering with the determination of the refractve index, which in the silts is often the only optical constant determinable with any degree of accuracy.

The mineralogy of the clays is far from satisfactory. There are many clay minerals described from analysis, but little is known of those physical properties of value in identifying these under the microscope. It is a question indeed if any but a few of these are

really homogeneous enough to be properly classed as minerals. It would be of value to mineralogy if this matter could be satisfactorily cleared up and these so-called clay minerals certainly identified.

Some idea of the origin of clay deposits may be obtained by microscopic examination. The feldspar content of clays varies; in some, feldspar is almost entirely absent; in others, considerable of the feldspar is present. At times, in the microscopic examination of clay deposits, the spicules of sponges and rhizopoda casts are found, which indicates an origin by deposition in shallow water, generally inclosed basin and swamp or pond conditions. The feldspar content of such deposits is very low. Diatomaceous earth deposits are distinguished from a true clay by examination with a high power objective. The diatoms are readily recognized by their circular or elongated forms and by their elaborate sculpturing, Volcanic ash deposits are distinguished from clay, since the former is amorphous and does not transmit light between crossed nicols and is also seen to be quite angular in outline when a high power objective is used.

Residual clays from limestones carry tiny crystals of quartz often doubly terminated. These crystals of quartz may enclose particles of calcite. Residual clays from limestone in the region of free rainfall do not carry calcite to any extent. In clays derived from the disintegration of basic igneous rocks, chlorite is quite common, the iron of the ferromagnesium minerals separating out as oxide, the magnesium uniting with the silica and aluminum to form chlorite. Microcline, muscovite and epidote, are common minerals found in clays and associated with these are the more insoluble minerals rutile, zircon and tourmaline. These minerals do not yield readily to weathering influences; muscovite takes up a little water and loses its flexibility, but retains its optical properties. Biotite decomposes quite readily with the separation of iron oxide and the formation of chlorite. Quartz is a constantly associated mineral.

The mineralogical examination of commercial clays should be undertaken where it is possible, since it affords another means of valuing clays which is supplementary to the chemical analysis. It is unfortunate, however, that this method has its limitations, which at this time prevent the accurate identification of the very fine particles.

THE VISCOSITY OF PORCELAIN BODIES[1]

BY A. V. BLEININGER AND PAUL TEETOR

INTRODUCTION

The vitrification of ceramic bodies requires for its explanation two assumptions, the existence of a considerable superficial force tending to contract the mass and lowered viscosity or softening which will permit the displacement and rearrangement of the molecules. The existence of surface tension must be considered as proven in the light of many physical phenomena. Likewise there can be no doubt as to the softening of the body, since the deformation observed only too frequently clearly indicates such a condition.

EXPERIMENTAL PART

Owing to the fact that no numerical values are available with reference to the degree of softening of ceramic bodies, it was thought desirable to carry on experiments with the purpose of determining the degree of viscosity reached by a series of bodies of the porcelain type. As a measure of viscosity the deformation under tensile strain was used. For this purpose specimens of porcelain body were made up of such shape that they could be hung from a fire clay grid and a weight attached to the bottom. The shape and dimensions of the pieces are shown in the diagrams of Figure 1. The length of the square bar between the end pieces was 4.5 inches and the width 1.112 inches, mold measurements. It was desired to have specimens possessing a cross section of approximately one square inch after burning them to vitrification.

The load was applied to each bar (after firing to cone 10) by means of a fire clay piece provided with a groove into which fitted the bottom part of the porcelain. It was decided to maintain the tensile load as closely at 5 pounds per square inch as possible. After burning the test bars their cross section was measured accurately by means of a micrometer caliper and the average cross section computed, based upon ten measurements. For each bar the weight of the corresponding fire clay load piece was then ad-

[1] By permission of the Director, Bureau of Standards.

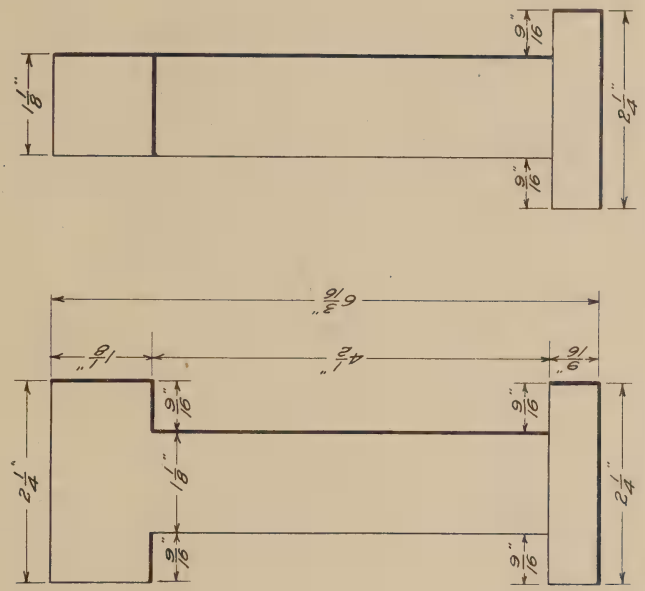
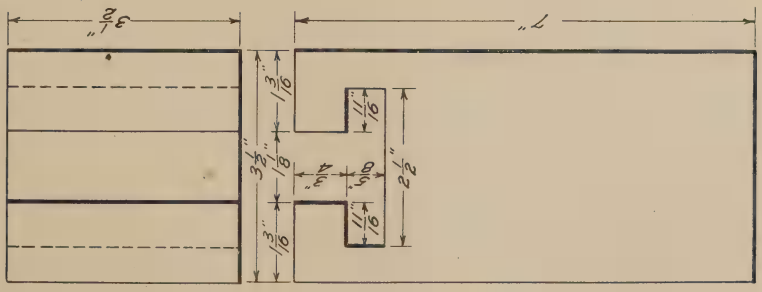


Fig. 1.

Bleininger & Teetor



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justed by chipping so that the initial tensile strain was exactly 5 pounds per square inch. The elongation was obtained by measuring the distance between two fine lines, 9 cm. apart.

The porcelain series embraced compositions ranging from 35 to 50 percent of clay and from 10 to 25 percent of feldspar. The clay material was introduced as North Carolina kaolin, Georgia kaolin and Tennessee No. 3 ball clay in the proportions of 5: 1: 1. In Table I the chemical analyses of the raw materials are given and in Table II the compositions of the bodies.

TABLE I

	NORTH CAROLINA KAOLIN	TENNESSEE BALL CLAY	GEORGIA KAOLIN	FELDSPAR	FLINT
	percent	*percent*	*percent*	*percent*	*percent*
Silica	45.84	50.80	45.69	70.79	99.23
Alumina	38.46	32.09	37.52	16.75	0.32
Ferric oxide	0.57	1.56	0.53	0.22	0.10
Titanium oxide	0.11	1.23	1.61		
Calcium oxide	0.19	0.18	0.18	0.24	0.08
Magnesium oxide	0.08	0.40	0.25	0.18	0.13
Sodium oxide	0.07	0.38	0.11	3.29	
Potassium oxide	0.35	1.14	0.20	8.26	
Loss on ignition	14.44	12.49	14.05	0.46	0.22
	100.11	100.27	100.14	100.19	100.08

The body constituents were ground together in the slip state in the ball mill for two hours, then screened and filter pressed. After wedging the mass, it was pressed into the shape shown. After thorough drying all of the specimens were fired to cone 10 before being subjected to the tension tests. The bars were then suspended from H shaped fire clay grids, placed firmly upon fire bricks, and the proper weight pieces attached to each. The firing for the tensile tests was carried to the following temperatures: 1065°C., 1100°, 1125°, 1160°, 1190°, 1220°, 1250°, 1280° and 1310°. Up to 800° the burning was carried at a convenient rate but from this point on great care was taken to raise the temperature at the rate of $33\frac{1}{3}$° per hour. Firing was stopped as soon as the proper temperature was reached. No elongation was observed until the 1160° burn.

TABLE II.—COMPOSITION OF BODIES

NO.	CLAY	FELDSPAR	FLINT
	percent	*percent*	*percent*
1	35	10	55
2	35	13	52
3	35	16	49
4	35	19	46
5	35	22	43
6	35	25	40
7	40	10	50
8	40	13	47
9	40	16	44
10	40	19	41
11	40	22	38
12	40	25	35
13	45	10	45
14	45	13	42
15	45	16	39
16	45	19	36
17	45	22	33
18	45	25	30
19	50	10	40
20	50	13	37
21	50	16	34
22	50	19	31
23	50	22	28
24	50	25	25
25	commercial porcelain body.		

The numerical results of the work are compiled in Table III. The ink test was applied to the bodies after burning them to the maximum temperature and noting the absorption of ink after washing off the spot with oxalic acid and water.

It will be noted from the table that complete vitrification as measured by the ink absorption takes place in no case with less than 19 percent of feldspar.

It is interesting to observe also that softening occurs at as low a temperature as 1160° only in the case of the larger feldspar contents, 22 and 25 percent, and even these amounts bring about lowering of the viscosity with the maximum clay content.

Small percentages of feldspar, 10 and 13 percent, cause soften-

TABLE III

NO. OF BODY	PERCENT ELONGATION						INK TEST AFTER FIRING TO 1310°	REMARKS
	1160°C.	1190°C.	1220°C.	1250°C.	1280°C.	1310°C.		
1					0.13	0.13	Strong stain	
2					0.25	0.27	Strong stain	
3				0.20	0.56	2.02	Stained	
4		0.14	0.34	0.76	1.83	4.35	No stain	
5	0.39	1.29	2.79	6.17	12.23		No stain	Partly pulled in two at 1280°
6	0.22	1.04	3.02	8.56			No stain	Partly pulled in two at 1250°
7							Strong stain	
8							Stain	
9					0.28	7.40	Strong stain	Partly pulled apart 1310°
10				0.94	4.22		Faint stain	Partly pulled apart 1280°
11		0.36	0.93	2.72	4.77		No stain	
12	0.34	0.62	1.40	3.14	7.01	7.62	No stain	Pulled apart 1310°
13							Strong stain	
14							Stained	
15				0.28	1.04	2.66	Stained	
16			0.28	0.95	1.99	3.65	No stain	Broke at 1310°
17	0.17	0.25	0.85	2.03	4.09	6.14	No stain	
18		0.34	0.73	1.52	3.37	5.02	No stain	
19							Strong stain	
20							Stain	
21						1.15	Faint stain	
22				0.17	0.96	1.49	No stain	
23				0.25	1.01	1.80	No stain	
24			0.26	0.59	1.53	2.49	No stain	
25			0.14	0.39	2.01	4.08	No stain	Broke, 1310°

ing only with a low clay content, 35 percent, and then only at 1280°. Even with 16 percent feldspar, elongation does not appear until 1250°–1280° has been reached. High spar contents on the other hand show deformation at as low a temperatire as 1160° with 35 percent of clay.

The decreasing effectiveness of the fluxing constituents in bringing about softening with increasing clay is clearly shown, inasmuch

as with 50 percent of clay and 25 percent feldspar elongation does not begin before 1220°.

The diagrams of Figures 2, 3, 4 and 5 illustrate the elongation behavior of the bodies for the clay contents of 35, 40 and 45 and 50 percent.

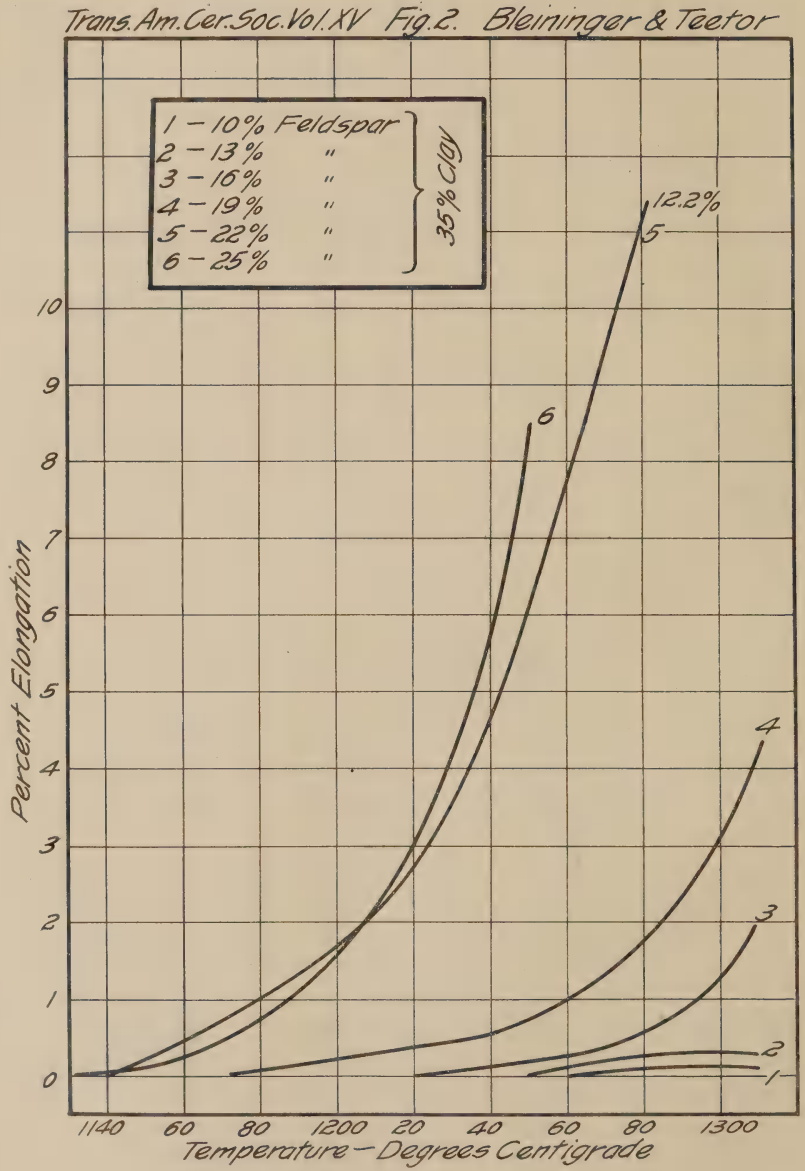
In the 35 percent clay series, Figure 2, a sudden decrease in viscosity seems to occur between 19 and 22 percent of feldspar. The latter amount is clearly excessive for this body. It would seem as if up to 19 percent the feldspar formed a viscous solution with the other constituents, while at 22 percent it is in excess and due to its own low viscosity caused the body to soften rapidly.

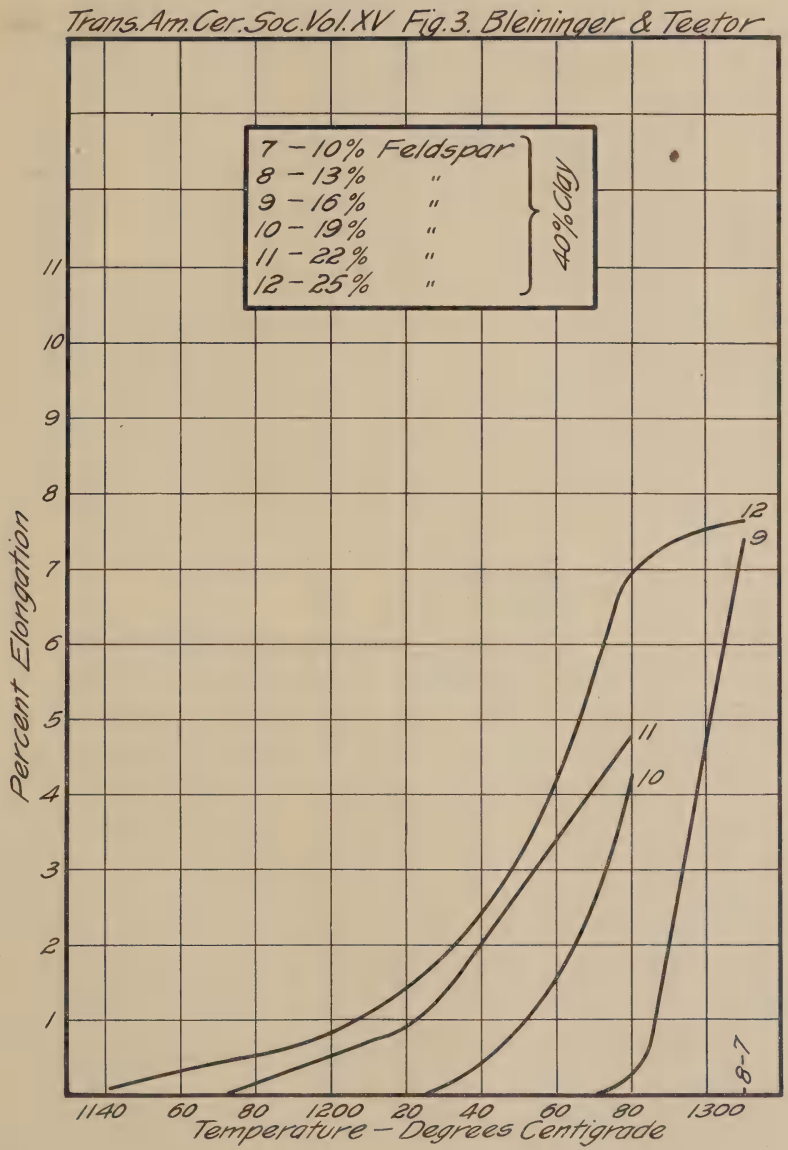
From this it appears that it is rather important to fix the feldspar content at the lowest value consistent with the desired physical properties.

In the 40 percent clay series, Figure 3, the curves are grouped together much more closely and no such sharp break is observed, for which behavior the increased clay content is undoubtedly responsible. The elongation values are also smaller, i.e., the viscosities greater. The curves, however, are quite steep, indicating a rapid decrease in viscosity or softening with temperature which is not a desirable condition.

In Figure 3 not only is a regular gradation observed between the different feldspar contents of the 45 percent clay series but the curves are very much less abrupt and thus indicate more gradual changes in viscosity between given temperatures. The rate of viscosity change is proportional to the feldspar content. The deformation values are considerably lower than for the 40 percent clay series.

The diagram of Figure 4 (50 percent clay series) shows a marked drop in the deformation values from the preceding bodies. The viscosity thus has increased very decidedly, which means lessened deformation. It is noted also that the effect of the feldspar increase is very much less marked than in the preceding cases. The rate of decrease in viscosity with rise of temperature also is very much less pronounced in this case.


Trans. Am. Cer. Soc. Vol. XV Fig. 2. Bleininger & Teetor
1 – 10% Feldspar
2 – 13% "
3 – 16% "
4 – 19% "
5 – 22% "
6 – 25% "
35% Clay
12.2%
Percent Elongation
0
1
2
3
4
5
6
7
8
9
10
1140
60
80
1200
20
40
60
80
1300
Temperature – Degrees Centigrade


Trans. Am. Cer. Soc. Vol. XV Fig. 3. Bleininger & Teetor
7 – 10% Feldspar
8 – 13% "
9 – 16% "
10 – 19% "
11 – 22% "
12 – 25% "
40% Clay
Percent Elongation
1 2 3 4 5 6 7 8 9 10 11
12
9
11
10
8-7
1140 60 80 1200 20 40 60 80 1300
Temperature – Degrees Centigrade

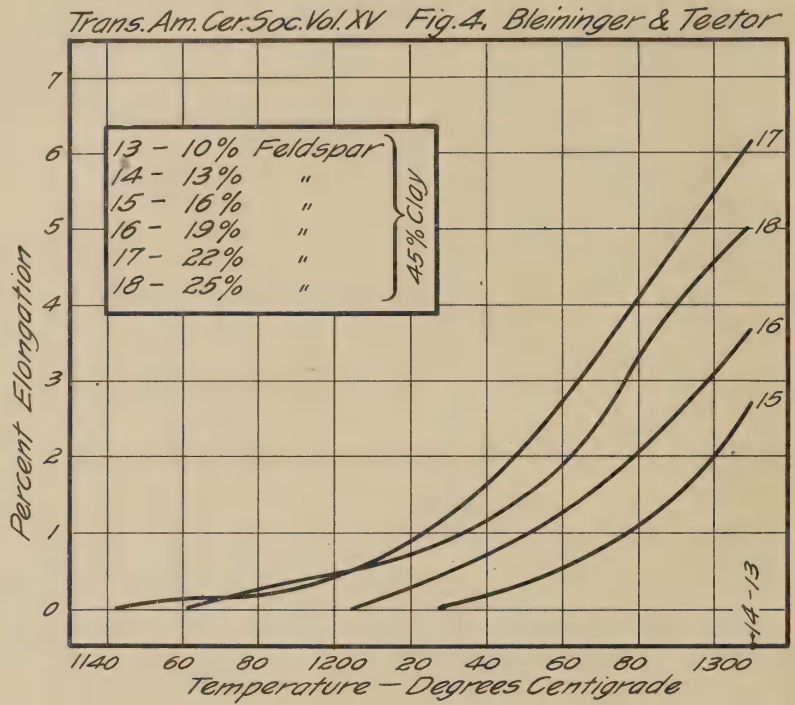
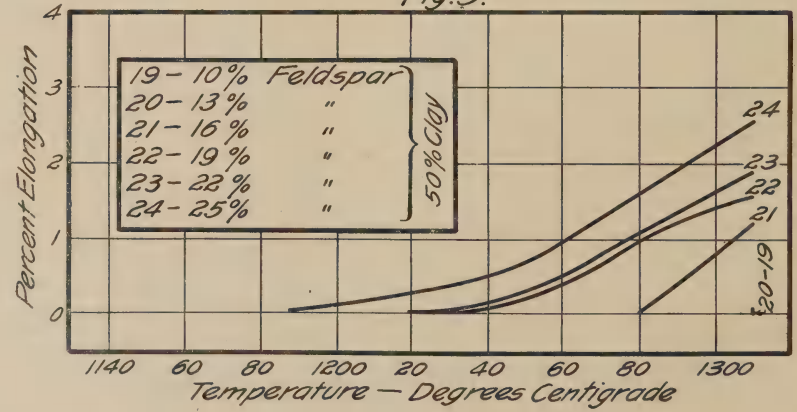

Trans. Am. Cer. Soc. Vol. XV Fig. 4. Bleininger & Teetor
13 – 10% Feldspar
14 – 13% "
15 – 16% "
16 – 19% "
17 – 22% "
18 – 25% "
45% Clay
Percent Elongation
0
1
2
3
4
5
6
7
17
18
16
15
14-13
1140
60
80
1200
20
40
60
80
1300
Temperature — Degrees Centigrade

Fig. 5.


19 – 10% Feldspar
20 – 13% "
21 – 16% "
22 – 19% "
23 – 22% "
24 – 25% "
50% Clay
Percent Elongation
0
1
2
3
4
24
23
22
21
20-19
1140
60
80
1200
20
40
60
80
1300
Temperature — Degrees Centigrade

CONCLUSIONS

From the foregoing results, it seems then that for the temperatures and the raw materials under consideration complete vitrification is not possible with less than 19 percent of feldspar. Excess of feldspar is undesirable owing to the lowered viscosity brought about by it. The higher the clay content the less marked does the effect of feldspar become. A sharp line of demarcation appears between the bodies containing less than 45 percent clay and those of higher clay content. The former possess a very much higher temperature coefficient of viscosity decrease and hence are more subject to deformation. A lower clay content than 45 percent is hence undesirable and may explain the difficulties experienced with bodies of the Seger porcelain type. The strength of porcelain bodies under tensile stress at the kiln temperatures considered has been found to be quite low, approaching 5 pounds per square inch quite closely with maximum elongation and is but a small fraction of the tensile strength at ordinary temperatures.

As to the permissible numerical elongation value under a load of 5 pounds per square inch, no exact deductions can be made but it probably lies between 5 and 6 percent.

This method of determining the viscosity of bodies at kiln temperatures has been found satisfactory. It is proposed to extend it to the study of clays and shales using a different form of bar, which is shaped at the ends like the heavy part of a cement brickette and which has measuring marks 100 mm. apart.

NOTE ON THE ELECTRICAL SEPARATION OF CLAY[1]

BY A. V. BLEININGER, PITTSBURGH

INTRODUCTION

A new electrical process for the purification of clay[2] which originated in Germany is causing wide spread interest. The treatment consists in stirring the clay with water and removing the coarse material by means of screens and settling. A previously determined amount of electrolyte is added and the suspension conveyed to the "osmosis" apparatus where it is electrolytically deposited on the positive electrode which is in the form of an endless belt. The clay is scraped off and conveyed to the dyers. It is claimed that the product contains only 25 percent of water and is free from pyrites, sand, or other impurities, has a lower alkali and a higher alumina content and is greatly improved in plasticity, bonding power, refractoriness and uniformity.

It was thought desirable to examine the principle under which this process operates and to carry on a few experiments intended to bring out more clearly some of the factors involved.

THEORY

It has been known for a long time that when small particles of matter are in suspension between two electrodes they will move towards either the cathode or the anode. This phenomenon is called kataphoresis. Suspended particles of shellac, clay, quartz, cotton, silk, starch, graphite, sulphur, etc., travel to the positive pole.

Small particles in suspension are always electrically charged and according to the character of the charge, + or −, they migrate to the negative or the positive pole.

The medium in which the fine grains are suspended is of great importance in governing the kataphoresis. In pure water most substances are charged negatively. Water itself is positive and

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[1] By permission of the Director, Bureau of Standards.

[2] *Tonindustrie Zeitung*, 36: 1283-85. *Transactions Engl. Ceram. Soc.* 12: part I, 36-65.

in electro-endosmosis moves towards the negative pole. No electro-osmotic effect are noted in liquids like chloroform, ether, petroleum, oil of turpentine, etc. For particles suspended in gases very high voltages must be employed in order to ionize the gaseous molecules and bring about precipitation as is shown in the Cotrell process. The addition of electrolytes to solutions used in kataphoresis brings about far reaching effects. According to Freundlich[3] "it is to be expected that the addition of OH′ ions in a negatively charged particle would raise the kataphoretic migration velocity to the positive pole while acids and cations of higher valency would decrease it with increasing concentration, reduce its value to zero and finally change its sign. With positively charged small particles the OH′ ion and the anions of higher valency are active in the same direction."

Whitney and Blake[4] found that upon adding 0.004 normal nitric acid solution to colloidal silver the particles originally migrating to the positive pole reversed their direction. A similar reversion was shown upon the addition of aluminum sulphate.

It is evident that the effect of additions of electrolytes must be complex in character since the flocculating action of the salts is involved as well as the question of the electrical charges.

The velocity of migration of fine particles seems to be independent of their size and shape, within certain limits. It is interesting to note that the migration velocity does not differ considerably from the value given for the more inert ions like sodium. While for the latter this constant is 43 by 10^{-5} cm. per second for a drop in potential of 1 volt per cm, the velocity of quartz particles, averaging 0.001 mm. is 30 by 10^{-5} cm. under the same standard conditions.

The process of electrical purification may be said to consist of three operations, the blunging and screening of the clay, the treatment with electrolyte and the separation upon the electrode. It is evident that the washing process in itself accomplishes a great deal in removing impurities such as coarse quartz, feldspar, iron pyrites, etc. In order to afford a strict comparison, it is not fair to compare the electrically treated with the crude material.

[3] *Kapillarchemie*, p. 239.
[4] *Jour. Am. Chem. S c.* 26: 1339.

The difference between the washed clay and that treated by the new process must be used to establish the merits of the case.

As has been pointed out by the inventors, the additional separation brought about by the use of electrolyte is really the most important factor in the scheme. By the proper treatment with small amounts of chemicals the viscosity of the slip may be decreased so that considerable quartz and feldspar ordinarily held in suspension may be thrown down. The suspended material thus remaining is, of course, of greater purity, and the deposit attached to the electrode should therefore be clay of better grade than that which is obtained by the ordinary washing. It is obvious that the same treatment can be applied where the slip is to go through a filter press, there being needed only adequate tank facilities for the separation of suspended matter. The electrical treatment in itself has very little to do with the purification, since all coarse impurities have already been removed by the previous precipitation treatment. The manner of deposition upon the electrode is of a mechanical character and takes the place of filter pressing, having of course the advantage that the process is continuous and automatic. Other mehods of separating the clay fron the water might be employed.

EXPERIMENTAL WORK

In the present work it was thought advisable to collect further information, (a) in regard to the reagents most suitable for the treatment preliminary to the actual separation and the determination of the proper amount to be used; (b) in regard to the behavior of different materials such as quartz, feldspar, ferric oxide and several types of clay when subjected to the electrical treatment.

a. It was found, in agreement with Ashley's work, that sodium hydroxide and sodium oxalate are the most effective reagents, the former to be used in the majority of cases, the second substance being particularly suitable in the case of fire clays. For the purpose of determining the proper amount of the reagent, viscosity determinations by means of the efflux tube were found most convenient. The method of procedure was to add small quantities of NaOH to the slip, making viscosity readings until

the minimum point of the curve was reached. This consistency proved most suitable for the electrical separation. In cases where the sodium hydroxide was found to be less effective, resort was had to the use of $Na_2C_2O_4$. In this simple manner the proper conditions are readily obtained. Indiscriminate additions of chemicals will lead to misleading results and unsatisfactory separation. The amount of the reagent necessary is small and rarely exceeds 0.2 percent in terms of the dry weight of the clay. An excess of the reagent must be avoided in all cases.

b. The work dealing with the electrical separation of suspended materials was mostly done by means of a very simple apparatus. A 220-volt direct current was available, controlled by two water rheostats. The separating receptacle was a copper can, 6 inches in diameter and 5 inches high. This was filled with the slip and a carbon electrode just immersed. Electrical connections were made with the can and the electrode. The latter was simply a carbon plate, of which there was a stock at hand. In the commercial apparatus it is said that the positive electrode consists of type metal. By means of a volt and ammeter the current was controlled.

For handling larger quantities of material an automatic apparatus was built consisting of a copper tank $5\frac{3}{4}$ inches by $6\frac{1}{2}$ inches by $7\frac{1}{4}$ inches, in which a revolving drum 5 inches in diameter and $4\frac{3}{4}$ inches wide, insulated from the tank, was used as the positive electrode. The clay adhering to the surface of the drum was scraped off at the opposite side. A slow moving stirrer was also provided at the bottom of the tank to prevent undue separation. A flush hole was arranged for washing out the residue after each run.

In the following paragraphs the results in the electrical separation of several materials are described.

Flint. Finely ground flint was found to separate well forming a dense layer at the positive electrode with voltages varying between 125 to 180 and a current strength of 0.75 ampere. It was a curious fact that with this material the deposition upon the electrode was most satisfactory without the addition of any electrolyte.

Feldspar. With a sample of Brandywine feldspar which was rather coarsely ground practially no separation took place with or

without electrolyte. Using Maine feldspar deposition occurred but not as marked as with the flint. The voltage used was 160, with 0.75 amperes. The addition of electrolyte produced no increase in yield.

Ferric Oxide. Finely divided ferric oxide in suspension formed no deposit with or without electrolyte. An addition of 6 per cent of this oxide was then made to North Carolina kaolin, and the treatment carried out upon this mixture. Upon determining the ferric oxide in the original mixture and the portion separated on the electrode, it was found that no reduction in the iron content was accomplished whatever. All of the ferric oxide admixed with the kaolin was carried along with the clay particles.

Kaolin. Inorder to determine whether further purification could be brought about with washed clays, runs were made with North Carolina and Florida kaolin. In both cases heavy, firm deposits were obtained with a content of 0.2 per cent caustic soda with voltages varying from 80 to 160, but chemical analysis showed no improvement. Practically all matter in suspension was carried to the electrode. The densest layer is obtained with the highest voltage.

Impure Fire Clay. A fire clay of the No. 3 type, from Aultman, Ohio, was ground to pass the 40 mesh sieve and made into a slip showing minimum viscosity with 0.1 percent caustic soda. The separation took place very satisfactorily. Upon making brickettes from the original clay the separated portion and the residue, the linear drying shrinkages were found to be 8.4, 7.5 and 6.25 percent respectively. Upon burning the speciments to cone 9 in a sagger, the separated portion was decidedly superior in appearance, showing a uniform light gray color, while both the original clay and the residual part were darker and showed numerous black spots.

In connection with these experiments the reverse effect, that of the negative electrode upon plastic clay, was briefly verified. Upon making a steel trowel the negative pole, it was found that water was drawn fron a mass of plastic clay into which the tool was inserted and thus caused the latter to penetrate very readily. This confirms the results reported in a paper before the 1912 National Brick Manufacturers Convention at Chicago.

CONCLUSIONS

In summarizing the results obtained in this work it might be said that the use of the electrical current in the treatment of clays plays no primary part in the purification process. Its function is that of mechanically depositing particles in suspension upon the positive electrode. It thus replaces the filter press and, if this can be done sufficiently economically, it certainly has the great advantage of simple, continuous and automatic operation. For the elimination of the undesirable impurities, the preliminary sedimentation process is of primary importance, since it is at this point that the objectionable material is removed. The use of caustic soda and other electrolytes brings about a condition of minimum viscosity which greatly assists in the separation of quartz and feldspar. It seems hopeless however, to expect that finely divided ferric oxide can be removed in this way.

It is intended to carry on further work in this connection. The results obtained in these preliminary experiments are not extensive enough to warrant a statement as to the commercial importance of the new process. It is to be hoped that it will prove of service in clay washing, where all the help that can be gotten along such lines is sorely needed.

DISCUSSION

Mr. Sincoe: While I may be altogether off the track, I would like to ask Mr. Bleininger if the presence of water is absolutely necessary for the attraction of these particles by electricity?

Mr. Bleininger: Yes, it is necessary. The minute you stir up the suspension, the conductivity increases very rapidly because each particle carries its charge of electricity. A point which I failed to bring out is that the plasticity is improved; the product is evidently more plastic than the material with which you started.

Mr. Sincoe: The reason I asked that question is that in Trenton recently the potters were called together to meet the Commissioner of Labor to thresh out a means to get rid of the dust in the factories, and most of the methods that were in common use created drafts in the factories and that was bad for the employees, and for the ware; and it was brought out in that meeting that a method

of settling the dust by electricity was being worked in California somewhere. Now if that could be accomplished it would be a great thing for employer and employee. Scientific research in this direction might bring about a new era in the pottery industry.

Mr. Bleininger: Mr. Cotrell, of the Bureau of Mines, has solved this problem, and I am quite sure that if you write to him he will give you the information you need. He is the greatest authority on the subject in the country, and has accomplished a great deal in regard to dust collection.

Mr. Watts: I would just mention, in connection with this process that Prof. Bleininger has been discussing—it is written up and described somewhat in Sprechsaal and also an American patent has been taken out by these people on this electrical separation of clays and it is in operation. You will include in your paper the references to the operation of plants?

Mr. Bleininger: In the introduction of my talk I referred to the original work done in Europe and of course, I shall also include this in the paper. The object of the work done by us was simply to analyze the conditions prevailing during the separating process and to determine, if possible, its limitations.

STRENGTH OF CLAY BARS AS INFLUENCED BY THE TEMPERATURE OF DRYING

BY C. H. KERR AND R. J. MONTGOMERY, TARENTUM, PA.

Preface. It is exceedingly probable that strength tests made upon raw clays have much greater inherent value than has usually been attributed to them. While many strength tests of various kinds have been reported, little or no actual use has ever been made of the data. It seems reasonable to believe that reliable data upon strength contains much more information than has ever been gotten out of it.

In connection with strength tests that have been made upon raw clays it has been the exception rather than the rule to give any description of the drying treatment preparatory to the testing. It has been recognized that the method and thoroughness of drying were of importance, but nevertheless little attention has been paid to this phase of the work. Some test specimens have been simply air-dried, some have been air-dried and then dried to constant weight at 60°C. or at about that temperature; but the most common method has been to air-dry the bars, then carry them to constant weight at 105°C. or 110°C. directly. That none of these methods of drying gives reliable and consistent results is shown by the data here given.

Materials Tested. St. Louis fire clay (washed) was selected for the experiment because it was considered to be in many ways an average clay, showing rather high plasticity and bonding power for a refractory clay. In addition to the St. Louis fire clay alone, another series of tests was run using 50 percent St. Louis fire clay raw and 50 percent of the same clay burnt and ground to pass a 10-mesh woven wire screen with wire about 0.030 inch diameter. This addition of 50 percent grog renders drying easy, and if variations due to differences in drying temperatures were found in this series, such effects must be very marked or they would not appear. Furthermore the use of 50 percent grog makes a series representative of a wide range of clays and clay wares in which the raw material is fairly lean or contains more or less non-plastic material.

Method of Testing. In all tests the clay was mixed to the best working consistency and then permitted to stand in a moist chamber for two days, wet. Bars, 5 inches by $1\frac{1}{4}$ inch by $\frac{3}{4}$ inch were made. All bars were dried in the air for seven days under ordinary room conditions before being subjected to the drying treatments described.

With the St. Louis fire clay alone, bars after standing in the air for seven days were divided into five groups. The first ones were broken in the air-dried condition without further drying. The second were put into an electric drying oven with automatic temperature control in which the temperature was 60° C. They were held at 60° C. until constant in weight and for one hour thereafter. They were then transferred to a desiccator over H_2SO_4, and when cold were broken by the transverse method, the bar being placed on supports four inches apart and a constantly increasing load applied at the middle until breaking occurs. The modulus of rupture was then calculated. The third, fourth and fifth groups were handled in the same way, being dried at 100°, 120°, and 150°C. respectively, in each case the oven being at the designated temperature when the bars were introduced. Introduction of the bars cooled the chamber, and usually about one-half hour was required for recovery to the required temperature. The modulus of rupture was calculated according to the formula:

$$W = \frac{3Pl}{2bd^2} \text{ or with } l = 4 \text{ inches}$$

$$W = \frac{6P}{bd^2}$$

when W = Modulus of rupture in lbs. per sq. in.
P = Load in lbs.
b = Breadth of bar.
d = Depth of bar.

The mixture of 50 percent St. Louis fire clay and 50 percent grog was handled in the same general way, but the drying temperatures were 40°, 60°, 80°, 90°, 100°, 110°, 120° and 140° C.

The results of the work outlined above showed, that if drying were done below 100°C., full strength was not developed; but on the other hand, if drying were done directly at a temperature above

100°C. (after it had reached air-dried condition), the structure was destroyed by too rapid drying. Therefore, the following combinations of drying temperatures were tried with the mixture containing 50 percent grog. In each case the bars were air-dried for seven days and then dried to constant weight and held for one hour longer at each temperature before proceeding to the next higher temperature. The combination temperatures were, 60–90–110°C., 90–110° C., 90–110–140°C.

Data. The St. Louis fire clay alone when dried in the air for seven days and then at the given temperature as described above gave the results shown in Table 1. The data is shown graphically in Figure 1.

TABLE 1

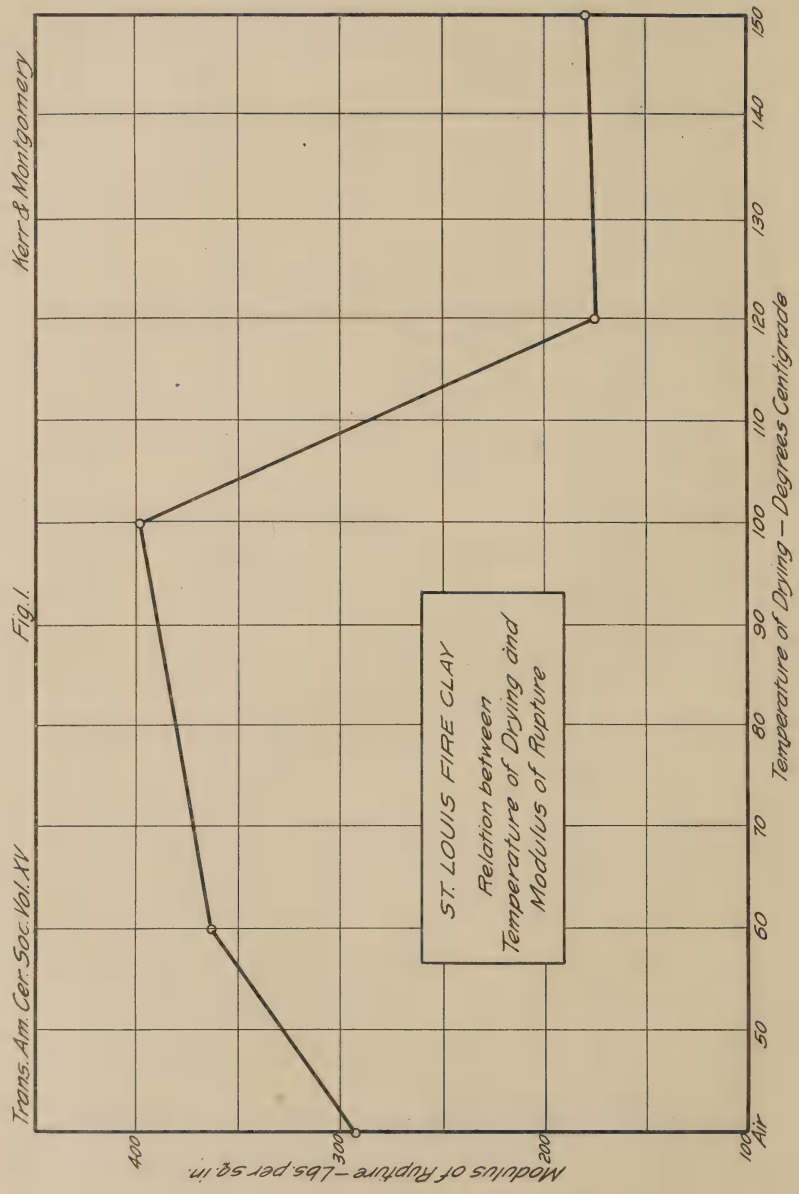
	AIR-DRIED	60°C.	100°C.	120°C.	150°C.
1	294	334	433	274	274
2	276	371	460	165	198
3	334	369	402	165	178
4	263	371	359	201	173
5	304	381	360	104	76
6	295	369	367	127	163
Average...	294	366	397	173	177

The mixture of 50 percent raw clay and 50 percent grog gave the results shown in Table 2, and Figure 2 shows the same in graphic form.

TABLE 2—50 PERCENT ST. LOUIS FIRE CLAY + 50 PERCENT GROG
Modulus of Rupture when Dried at Different Temperatures

	AIR-DRIED	40°C.	60°C.	80°C.	90°C.	100°C.	110°C.	120°C.	140°C.
1	201	184	229	291	306	259	271	299	226
2	200	221	254	265	324	298	332	292	221
3	191	211	255	276	327	300	323	265	255
4	192	199	263	265		288	321	262	219
5	196	219	269	291			285	286	238
Average....	196	207	254	277	319	286	306	281	232

A study of the data of Tables 1 and 2 showed that full strength was not attained in drying at temperatures under 100°C., and that


Trans. Am Cer. Soc. Vol. XV
Fig. 1.
Kerr & Montgomery
ST. LOUIS FIRE CLAY
Relation between
Temperature of Drying and
Modulus of Rupture
Modulus of Rupture — Lbs. per sq. in.
400
300
200
100
Air
50
60
70
80
90
100
110
120
130
140
150
Temperature of Drying — Degrees Centigrade

drying above 100°C., if done directly at that temperature from the air-dried condition was not safe. It seemed necessary therefore to combine these results to obtain reliable results. The combinations tried were those given in Table 3 where the results are included.

TABLE 3—50 PERCENT ST. LOUIS FIRE CLAY + 50 PERCENT GROG
Modulus of Rupture when Dried at Different Combinations of Temperature

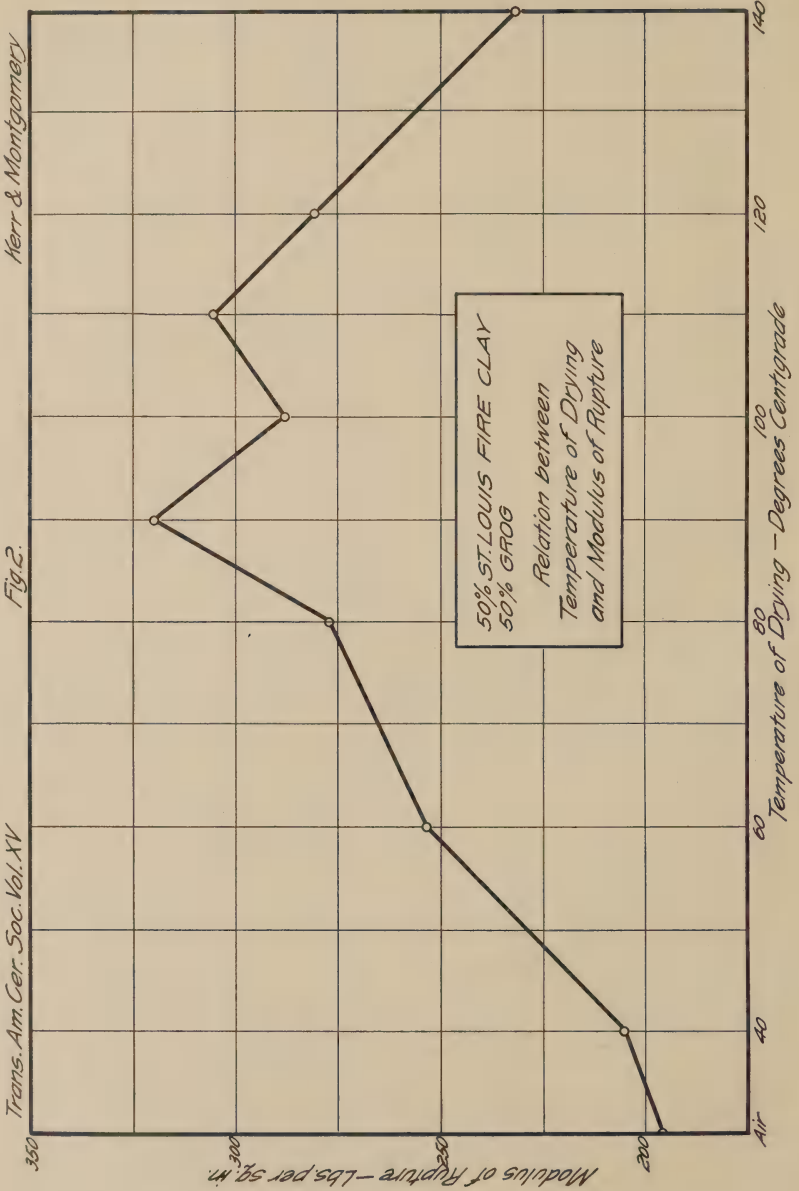
	60–90–110°	90–110°	90–110–140°
1	334	330	325
2	314	327	309
3	362	324	299
4	332	346	311
5		336	297
Average.....	335	331	308

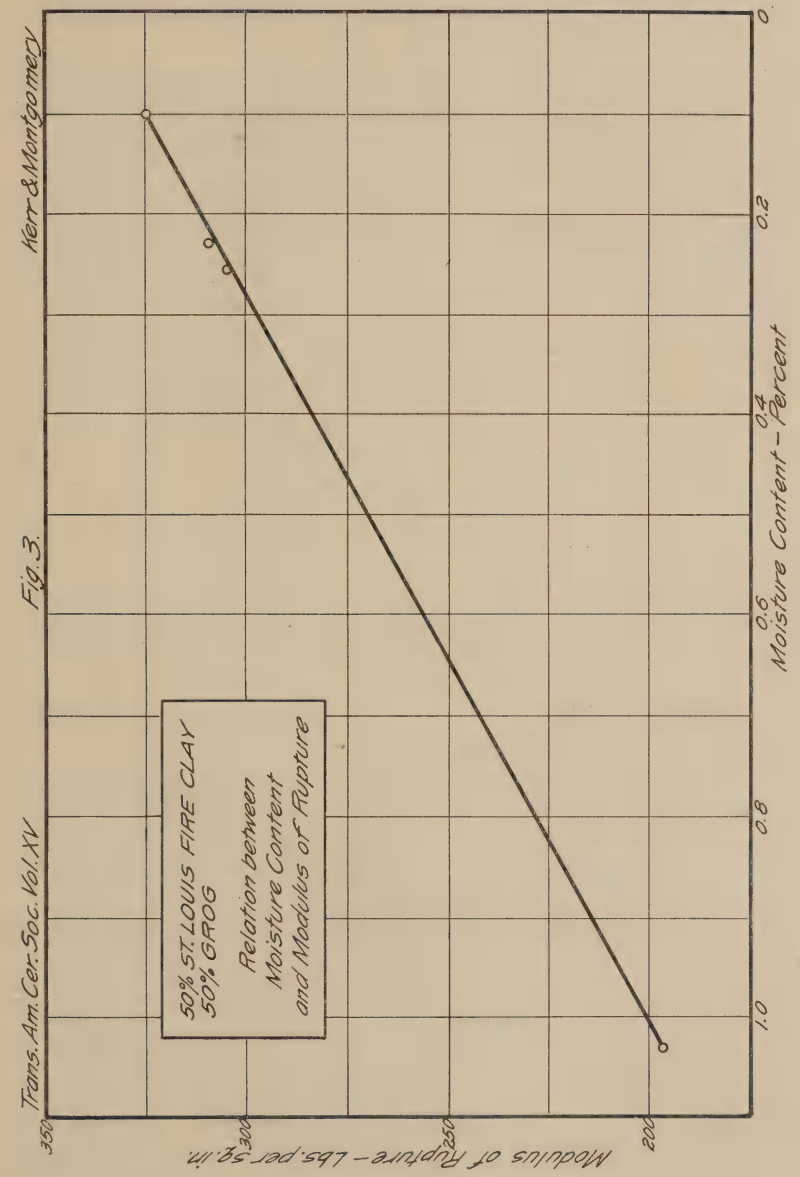
In addition to the above work on temperatures of drying, drying over sulphuric acid was tried. The results were fair. A very low water content could be obtained with accompanying high strength, but the method is too slow for ordinary laboratory use.

Relation of Moisture Content to Strength. It is of interest in connection with this work, to note the relation found between the water content of the dried test bars and their strength. After the bars were broken, their moisture was determined, and the average of the results is given below. These data are not offered as being of high accuracy or at all complete, but they suggest a relation of considerable interest (see Fig. 3).

TEMPERATURE	PERCENT WATER	MODULUS OF RUPTURE
Air-dried.....	1.03	196
60°C.....	0.26	306
Over H_2SO_4 six days.....	0.23	312
90°C.....	0.10	324

Discussion of Results. The data here presented has been substantiated by a very wide range of laboratory work, and it is very clear that the temperature of drying is of great importance in making strength tests of clays. Tests reported without specify-


Trans. Am. Cer. Soc. Vol. XV
Fig. 2.
Herr & Montgomery
50% ST. LOUIS FIRE CLAY
50% GROG
Relation between
Temperature of Drying
and Modulus of Rupture
Modulus of Rupture — Lbs. per Sq. In.
350
300
250
200
Air
40
60
80
100
120
140
Temperature of Drying — Degrees Centigrade


Trans. Am. Cer. Soc. Vol. XV
Fig. 3.
Kerr & Montgomery
50% ST. LOUIS FIRE CLAY
50% GROG
Relation between
Moisture Content
and Modulus of Rupture
Modulus of Rupture – Lbs. per sq. in.
Moisture Content – Percent
350
300
250
200
0
0.2
0.4
0.6
0.8
1.0

ing the drying treatment are of doubtful value. And there are certainly many cases in which drying is specified in which the drying treatment alone would condemn the work.

With St. Louis fire clay alone and with 50 percent grog (burned clay of the same kind) the results shown in this paper may be summarized as below.

1. Over 100 percent variation in the modulus of rupture of raw clay bars has been caused by variations in the drying treatment after the bars have reached the air-dried condition. The same general statement applies to the 50 percent grog mixture as to the raw clay, but of course the effects are sharper and more clearly defined in the case of clay alone.

2. It is evident that the strength of air-dried samples is very low in comparison with the results, when the bars are more thoroughly dried. In the air-dried condition either the clay alone or the 50 percent grog mixture shows not over 50 percent of its maximum strength.

3. Test bars dried at temperatures below approximately 100°C, do not attain full strength.

4. If air-dried bars are placed directly in an oven at temperatures above 100°C., they are disrupted by the rapid escape of water vapor.

5. When air-dried bars are dried to constant weight at temperatures safely below 100°C., and then further drying to constant weight at a temperature somewhat above 100°C., the results are good, showing that the higher temperature in itself does not cause low strength.

6. It is evident that for a reliable and satisfactory test, bars after being air-dried must be dried to constant weight at a temperature safely below 100°C. and then further dried to constant weight at a temperature somewhat above 100°C.

7. Within certain limits a definite relation is indicated between moisture content and modulus of rupture.

Summary. The application of the results is limited to St. Louis fire clay alone and the same with 50 percent grog or to such clays or mixtures as may be considered to be represented by these materials. Within such limitations the following statements will hold.

1. The modulus of rupture of raw clays varies enormously (over 100 percent) with the drying treatment after the test bars have become air-dried.

2. To insure reliable data the laboratory drying of test bars must embrace (*a*) air-drying, (*b*) drying to constant weight at a temperature safely below 100°C. (say 75°C.), and (*c*) a further drying to constant weight at a temperature above 100°C. (say 110°C.). Drying below 100°C. does not develop full strength and drying at above 100°C. directly causes rupture due to the rapid escape of water vapor.

3. A satisfactory drying treatment is the following:

a. Air drying for about seven days.

b. Drying to constant weight at 75°C.

c. Further drying to constant weight at 110°C.

DETAILS OF A SUCCESSFUL GRAVITY HAULAGE SYSTEM OPERATING UPON LOW GRADES

BY FRANK H. RIDDLE, ABBOTSFORD, B. C.

INTRODUCTION

One of the most important considerations in the establishment of a clay working plant is the winning of the raw material, particularly if heavy products are to be made. How the clay is obtained and handled is an important item which will show how its good or bad qualities when the factory has been in operation a very short time.

The factories situated near a hill, so that the clay is obtained directly behind and slightly above them, are very fortunate as compared with those that obtain clay from pits below factory level, or even below water level.

Wherever a gravity system can be used it should, by all means, be installed. A mine with a grade of 8 to 10 inches in the 100 feet will operate very well, for the empties can be pulled up the slight grade and the loaded cars will run down practically of themselves. When the grade in the mine, or out, increases to 4 to 8 percent, troubles begin, for the loads run away and the empties are hard to get back. Power will nearly always be necessary in cases of this sort. When the grade increases sufficiently, gravity can be used and arrangements made so that the loaded cars going down will pull the empties up. This is the ideal system and is well worth using wherever possible. The only question arising, when the grade is continuous, is on how low a grade will it operate. The steeper the grade, of course, the surer one can be that the system will work.

DESCRIPTION OF THE SYSTEM

Construction and Operation. The illustrations and sketch show a case where the grade varies very much and is not over 16 percent in the steepest part. The clay from one mine (No. 6) is brought out on a 1 percent grade and dumped down a steel-lined

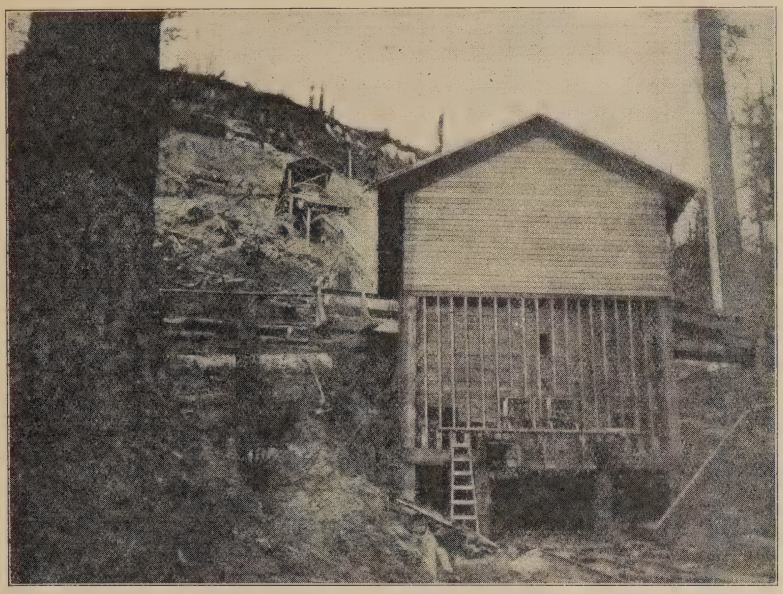


Plate I. No. 4 bunker, showing No. 6 tipple and chute in background. Note track on right going into bunker from No. 4 mine.

Plate II. Passing track on tram line

chute, 145 feet long. The grade is 33 degrees, and the speed of the clay accelerated so rapidly that it was necessary to install three very heavy swing doors at equal distances apart in the chute to check the speed. Ordinarily the clay slides very well; but in wet weather, before the chute was covered, the clay lumps would start to roll and the doors were very useful in checking the rolling, as well as decreasing the speed of the sliding clay. For a short time, the chute was operated without being steel-lined and was a failure, for the clay would not slide and had to roll. A ton would be dropped into the chute, and about a third would reach the bunker below. The rest would jump out. The steel lining overcame this at once.

The storage bunker at the foot of the chute stands at the head of the gravity tramroad in a position high enough for cars to pass underneath for loading. The clay slides through chutes at the bottom of the bunker to the cars. The gates for these chutes have proved very satisfactory and operate with ease.

When the tram was first operated, we expected trouble, for even the steepest part is of low grade for work of this sort, also because of the wide variation in grade. The lowest 250 feet is about 5.3 percent and the upper 250 feet is 13 to 16 percent grade. This means that when the loaded cars are near the bottom on the 5.3 percent grade, the empties are near the top on the 16 percent grade, and the difference in weight between the empties and loads must be great enough to take care of the added variation in grade, as well as the variation that would occur if the grade was continuous. The tram line is 1200 feet long having three rails and with a passing track at the center. The cable joining the cars runs around a friction head gear at the head of the tram. This can be operated at will and thus the speed of the cars can be controlled.

In starting, the heavy cars are on the steep grade and empties on the low grade, so that there is no trouble in gaining speed very rapidly; and it is necessary to apply the friction on the head gear until the cars pass. From here on, the variation in grade is the reverse, i.e., the loaded cars are going along on the low grade and the empties are going up the steep grade. The only thing which overcomes this difficulty is the momentum which the cars gather in the start on the heavy grade. To operate the tram properly

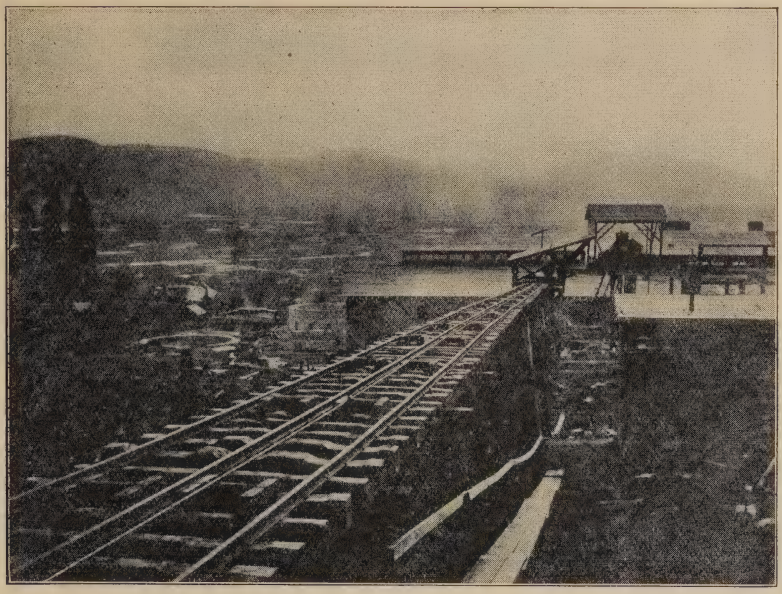


Plate III. Looking down the last three hundred feet of the tram. Showing the cable on rollers and cars at end of line, also elevator and track into the factory at the right.

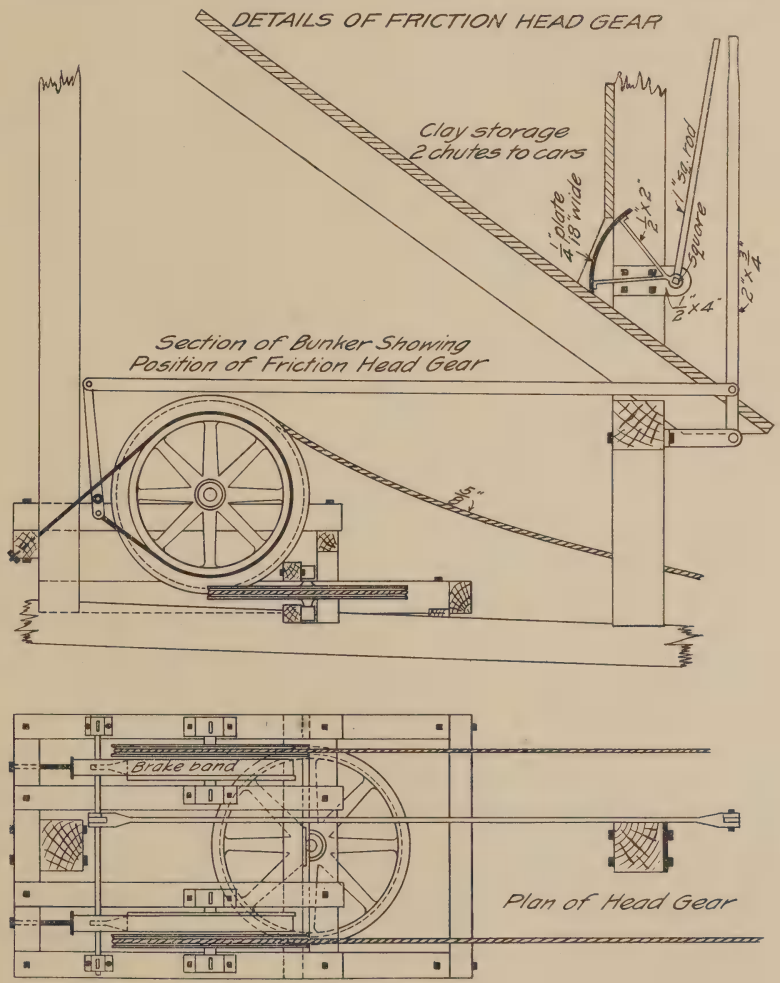
Plate IV. Tram line from bunkers and mines beyond at the left, and tracks coming into factory from the crusher and elevator at the foot of the tram line.

it is necessary to use considerable judgment in the beginning of the trip to secure just enough speed to produce sufficient momentum to carry the load down the low grade and to take the empties up the steep grade. If, for any reason, it is necessary to stop the loaded cars on the lower side of the passing track, it is not possible to start the system again. This shows that the momentum gained in the start is all that carries the cars over this part. A glance at the section drawing of the line will show why the system was built with the grade as it is. It would have been necessary to make a trestle the entire 1200 feet to have secured an even grade. This would have been ideal in operating, since the cars could have been stopped and started at will; but the first cost would have been great.

This same tram line is used for carrying our No. 3 and No. 4 clays as well as the No. 6 clay. The section drawing shows a bunker with two storage bins just down the hill from the No. 6 bunker. The clays are brought about 400 feet to this bunker from a mine around the hillside, on a grade of 10 inches to the 100 feet. In order that one man could operate the tram from any of the bunkers, it was necessary to cut sight holes in the front bunker so the position of the cars could be seen from the top bunker also from the upper section of No. 4 bunker. The lever operating the friction head gear was also extended by means of a connecting rod to the lower bunker; and levers were put in at each one so that the operator can stand at any bunker, open the gates to load the cars, operate the friction gear, and see the cars on the trip. If it was not for the extension of the gear levers, it would be necessary for the operator, in working the front bunker, to run down to it to fill the cars and then run back up to the head gear to let the cars down. The only other solution for this would have been two men.

In using the three bunkers on the one system, it is necessary to have the passing track long enough for the cars to pass when running from any bunker. The lower switch point must be three or more car lengths below the point midway between the spouts on the lowest bunker and the extreme lower end of the tram. The upper point must be the same distance above the point midway between the spouts of the upper bunker and the extreme lower

Trans. Am. Cer. Soc. Vol. XV Fig. 1. Riddle



end of the tram. It is also necessary to have two extensions on the cable so that the upper cars are in a position to be loaded at the same time the loaded cars are at the low end of the line being emptied. These extensions are the same length as the distances between the bunker spouts.

If the upper bunker is empty and it is desired to change and operate from the lower bunker, the operator lets the loaded cars down until the empties are in the proper place for loading from the low bunker and fastens the empties, so they will not run down the grade when the loaded cars are unfastened from the other end of the line. The loaded cars will stop the same distance from the lower end of the tram line as the empties do from the top, i.e., the distance between the two bunkers. The man who dumps the cars at the end of the tram then unfastens the loaded cars from the cable, pushes them down to the chute above the crusher and dumps them. He then lets out the extension cable and connects it to the cars. By the time the crusher has taken care of the clay just dumped into it and it has been taken to the proper storage bins in the factory, the man at the head of the tram has connected up his lever so he can operate the head gear from the low No. 4 bunker and has loaded the cars. When he lets these cars down the tram, the empties will stop at the proper place for loading from this same bunker, for the extension cable is equal to the distance between the two bunkers, as described above.

Capacity. At present the line is being operated with two, twenty cubic foot capacity, cars on each track. Each car averages about 1.1 tons, so that each trip means 2.2 tons of clay. The two cars can be loaded, let down, and unloaded in four minutes; and at the same time they are being unloaded, the other two cars are being loaded. This gives the line a capacity of 300 tons per day of ten hours, allowing 10 percent for delays. By using one car on each track, arrangement can be made for the cars to dump automatically and we could thus save the expense of the man at the foot of the line. At present the man there is not only dumping these cars but also taking the cars of crushed clay into the factory and dumping them into the storage bins. This also will be done away with as soon as a conveyor is installed.

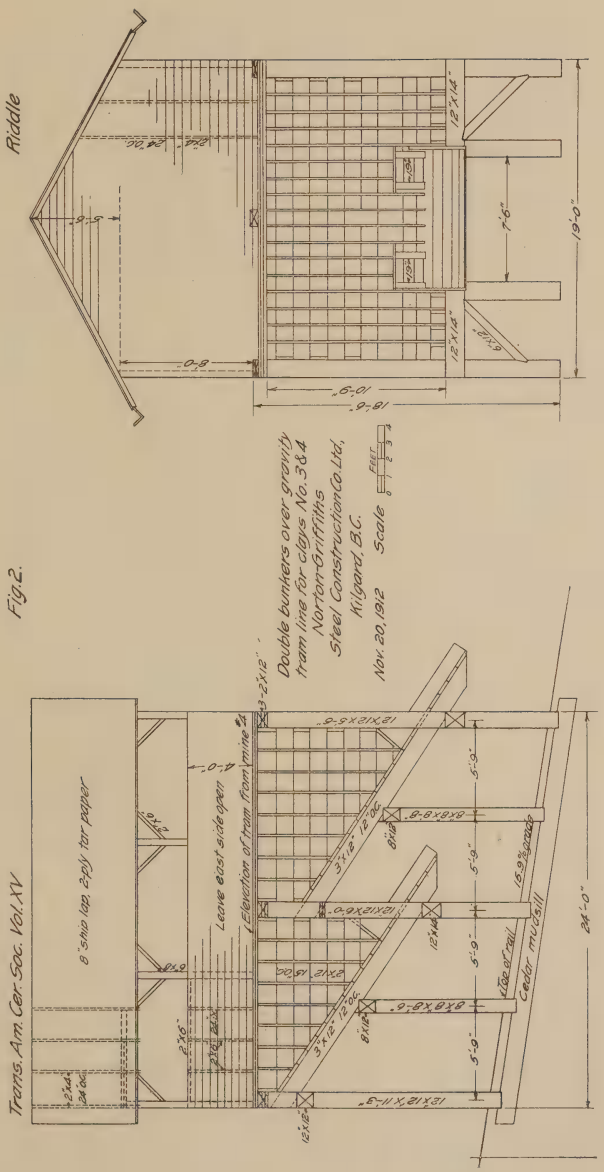

Riddle
Double bunkers over gravity tram line for clays No. 3 & 4
Norton Griffiths Steel Construction Co. Ltd.
Kilgard, B.C.
Nov. 20, 1912 Scale
Elevation of tram from mine
Leave east side open
6" shiplap, 2 ply tar paper
Cedar mud sill
Top of rail
24'-0"

Fig. 2.

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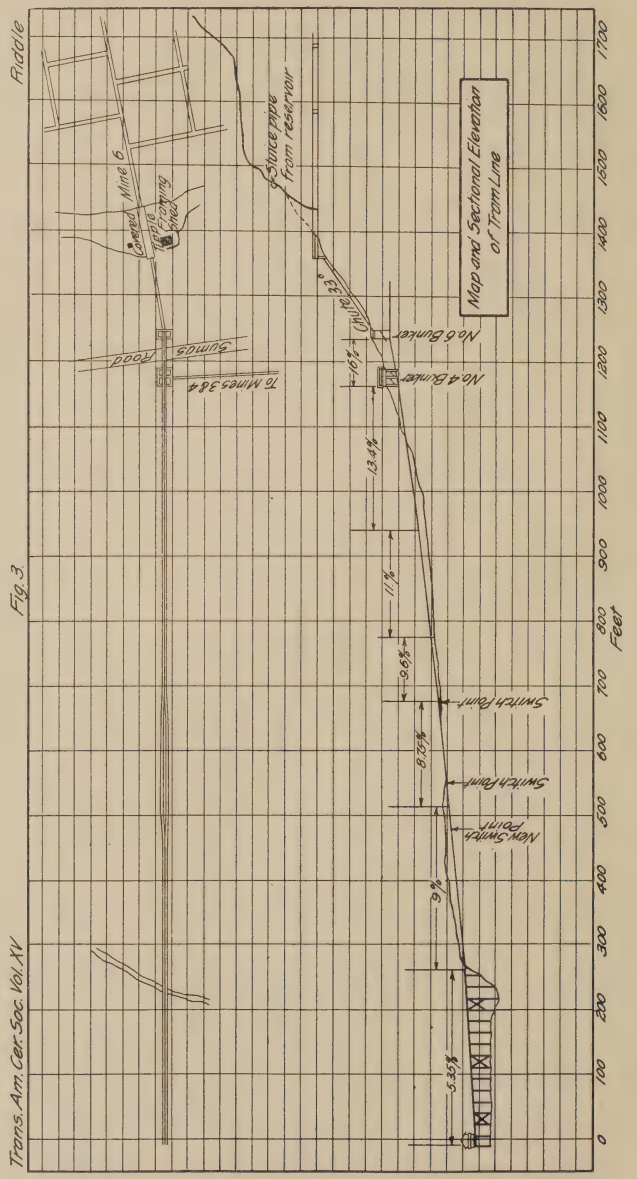


Fig. 3
Trans. Am. Cer. Soc. Vol. XV
Map and Sectional Elevation of Tram Line
Riddle
Sumps
Road
To Mines 3&4
No. 6 Bunker
No. 4 Bunker
Switch Point
New Switch Point
Feet
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700

CONCLUSIONS

Advantage. The advantages of the gravity system hardly require any remarks. Perhaps the greatest one is the fact that the capacity of the system is doubled, for where power is used to pull the car back there is not another car going down with a load as in the case of the gravity system. For some time the system was operated with power. A twenty-five horse power, donkey engine was used; and the system required a British Columbia licensed engineer, a wood cutter, and a man to load the cars. The gravity arrangement has doubled the capacity and saved the generation of twenty-five horse power. If it had been intended to use power permanently, a motor would have been employed so the labor cost would have been the same. The power would have cost considerable however.

Possible Modifications. Where the layout permits, a continuous grade of 12 or 15 percent would make a far safer system for operating, since the cars could be started from any point along the line. A four-rail system will also prove more satisfactory, for there are no bends in the track, which may cause wrecks when the cars are let down too fast. The cable will always run in the center of the tracks, and it will be much easier to keep on the rollers. The rollers will be of use more to keep the cable from wearing than to decrease the resistance caused by it rubbing along the ties.

An Additional Use. This system has since proved very satisfactory in making clay mixtures. In making fire brick, the clays were taken down to the factory separately and mixed in diaphragm cars; but now the tram cars are partly loaded at one bunker and then let down the tram to the next bunker and filled. In this way any mixture can be made very readily, and by the time the clay is dumped, crushed, elevated to cars, dumped in bins and run through the dry pans and wet pans, it is thoroughly mixed. Again if an error is made in the mixing of one car lot, it does not do the damage that would be done if the clay was mixed in a diaphragm car and dumped direct into a wet pan and made into brick direct.

POTTERY FIRING BY PYROMETRY

BY EDWARD C. STOVER

So much has recently been written on the subject of "Firing" (particularly in our Vol. XIV in "The Melting Points of Pyrometric Cones Under Various Conditions" by Samuel Geijsbeek and discussions accompanying) that it would almost seem there was little left to write about; but as more light on this difficult and uncertain part in ceramic productions will always be acceptable to the genuine student, I will venture to endeavor in this brief note to cover a few of the untouched though vitally important points.

The early firing that is commonly spoken of as "the water smoking," or in other words, "the driving out of the chemically combined moisture" not removable in the dryroom, occurs in firing the various ceramic products between lighting up and cherry-red heat, approximately 1688°F., 920°C., Seger cone 011., Wedgewood shrinking block trial 5. This vital point is reached at times varying from twenty hours to sixty hours, according to kind of product, size and construction of kiln, etc. A great many people do not thoroughly realize how important this early part of the firing really is, that the size of their scrap pile (which as we all know does not include profits) is very frequently determined during the very early stages in firing, and that this point is not indicated definitely and accurately by any of the old methods of firing, including the Seger cone method.

There is now in use in some plants in England and the United States a system of firing by withdrawing at stated intervals, of about five hours each, rings with holes in the center. By accurately measuring the swell or shrinkage of these trial rings, the firing is accomplished. This has been said by some one to be an application and modification of Joseph Wedgewood's shrinkage blocks and his system for measuring the same; but this is stoutly denied by the originator of the present system.

If knowing what progress is being made every five hours, or every hour in fact, is important in kiln firing, including the early stages while the swelling is going on and the chemically combined

water is being driven off, which is now admitted by some of our best and most experienced ceramists of the present day to be one of the most important times of firing kilns; a continuous knowledge of the progress of both tops and bottoms at various points, plainly recorded in ink on a chart, would seem to be additional valuable knowledge at this most particular time in firing. I do not claim that this method should supersede all others; but owing to the vast importance, risk, loss and cost during the firing period, anything that will shed more light into what is now the dark and dangerous corners should be added to what we already have, for a thorough trial and test, to see if the disappointments and losses from these sources can be minimized.

The busy foreman with years of experience, naturally knows a great deal about kiln firing; but under any of our old systems, he is wholly at the mercy of his fireman. By the aid of a reliable recording pyrometer, he can see at any time if the firing is progressing along the lines of his instructions. The fireman also can see at any minute of the day or night, by simply glancing at the ink record chart, the exact status of the various quarters.

By keeping these charts in file, and by noting on them just which kiln they represent, and final results after drawing, it soon becomes an easy proposition for the foreman to select one of a properly fired kiln as a sample chart for his fireman to go by in handling the future kilns. This system enables the firing to be controlled in a way that cannot be accomplished by any other yet devised. This is particularly true of the early stages of the firing, where so many of the losses are started.

NOTE SUBMITTED AFTER READING THE PAPER

Mr. Geijsbeek: It is very gratifying to me to note that Mr. Stover advocates the use of pyrometer in firing pottery kilns so that there can be obtained an accurate record of the heat of such kiln from start to finish. It is getting more and more known and understood that the sources of several losses in the finished clay products can be traced to the period in which the kiln is still black while under fire. The water smoking and the driving off of the chemical combined water are two stages in the burning

of clay products which cannot be handled by cones, and a pyrometer will greatly aid in getting more knowledge and data, and therefore more desired results, than anything so far adopted and in use in the burning of kilns for the clayworking industry.

The system of trial pieces which Mr. Stover mentioned appeals to me as being a good one, for it will give, in connection with a pyrometer record, additional information as to the physical condition and the chemical changes which take place in the burning of clay products at a particular stage and time of observation. He does not state the name of the originator of this ring with hole system, but very likely he refers to the Watkin system. In an article in the *Transactions of the English Ceramic Society*, 1902-03, Vol. II, Mr. Watkin[1] describes a pyrometer for pottery purposes based on the principle of the contraction of clay. This system is really too elaborate for practical use; but if simplified, it will work alright and give a great deal of valuable data for the burning of clay ware.

The water smoking period can be judged in most cases to a certain point of accuracy; and if a clayworker is troubled with watersmoking defects, it is due to his ignorance of the process of changes that take place while firing. A close study of the troubles will soon overcome the defects. The dehydration period during which the chemical combined water is driven off, has, however, not been subjected so far to any controlling device. While much data is available as to what takes place in that period of firing, nothing to any extent has been done to control this period, with the exception of a close observation of the pyrometer registering either increase or decrease of heat at that period.

Mr. Stover mentions that the shrinkage and the swelling of the clay will have to be observed. We have further the action of the gases to deal with, and these should be watched closely. Experience has shown that bodies, which under ordinary conditions will burn yellow in an excess of air current, will burn a more or less intense red when burnt in a current of sulphur gases. This same phenomenon has at times caused potters many losses and troubles by producing red specks in biscuit whiteware firing. It is caused

[1] *Transactions of the North Staffordshire Ceramic Society*, 1902, page 93.

by the sulphurous gases while firing acting on the iron contents of the setting sand. The data collected by A. Hopwood and W. Jackson, while conducting a large number of experiments to show the coloration of clayware while firing, gives an idea of the difficulties which kiln gases can cause in the early stages of the firing.

It must be born in mind that the chemical changes in clay are all produced by heat; and while we do not have any exact data as to when these changes take place, nor if they are alike for all clays, we are getting more and more intelligible data for handling this problem. The chemical changes that take place in other mineral products by heat applications are nearly always at the same temperature, and it is therefore safe to assume that the chemical changes in clay products take place under similar conditions. For the present while we have nothing better, it is therefore essential to have a pyrometer control of the kiln heat, and especially of the period of, so called black heat, which cannot be judged by eyesight and is invisible as far as heat rays are concerned.

A METHOD OF TESTING CRAZING OF WHITE WARE

BY HERMAN HARKORT, DRIESSEN, GERMANY

INTRODUCTION

The most important qualifications of white ware are density and immunity from crazing. Although white ware of defective density is often manufactured and finds a satisfactory market, a continuous production of ware which crazes is impossible. Such ware is almost worthless and finds no permanent customer. And yet almost every factory has this defect to combat ocasionally, if not continuously. This is especially true when changes in the crude materials, the clay in particular, are undertaken. At any rate, an astonishingly large sum would be found if the losses from crazing of white ware were compiled. That this is the case at the present time is due to insufficient knowledge of the influence of body composition upon the development of crazing.

The fundamental laws which Seger established in this matter on the basis of his investigations, are too general to provide clear and definite information for practical use. In particular, every assertion concerning the body and the range of the necessary changes fails. Seger went on the supposition that the real cause of crazing is the difference in the coefficients of expansion of body and glaze. Thus he exposed the fundamental cause for the phenomenon and established the investigations concerning it upon a scientific basis. But in connection with this, other important factors must be considered; and, if the concordance of the two coefficients was the sole possibility of correcting the crazing of the glaze, the manufacture of white ware would probably be an impossibility. In the *Transactions of the American Ceramic Society* reference has been made to the inadequacy of Seger's views.

The real reason for the insufficient knowledge concerning this vexing question is the fact that, up to the present time, there has been lacking a method for proving that white ware is reliable and free from objection in respect to the development of crazing. It is above all to be considered that a piece which leaves the kiln free from crazing may become crazed after the lapse of more or less

time, and that this often occurs in use. It must further be recognized that this does not always occur, however, and that more often objects remain free from crazing in spite of many years service. There is, therefore, a complete range possible, from immediate occurrence of crazing to absolute resistance to the crazing tendency.

In consideration of these conditions, it is clear that searching and systematic investigations, involving observations covering months or perhaps years, in which preservation of the objects under tests under the same conditions must be secured, presents an insurmountable difficulty. I know of no research which would be undertaken after consideration of this point. And yet, to establish whether the glaze may be relied upon for long continued service, is certainly more important than observing whether the crazing begins at once or not. The greatest loss in manufacture occurs when the ware becomes crazed a long time after being fired, since it has been thus far not possible to prove that the changes (in body composition) undertaken up to that time were leading to the goal. Without going further, it is clear that in this way years might pass before the goal would be reached, and that even then it could be retained only by clinging convulsively to the composition of body and glaze which had been won. In short, the impossibility of a craze-test for glazes has made impossible a deepening of the knowledge concerning this point, and has introduced an inflexibility in factory methods which alone makes it comprehensible that in entire districts ware is manufactured in an irrational and improper way, on the strength of an apparently unbreakable tradition. According to Seger's conception, the proximity of the coefficients of expansion of body and glaze ought to be determined. But apart from the fact that these determinations are too delicate and tedious for practical factory control, it is plain, as I shall later show in certain observations, that in spite of the difference in the coefficients of expansion, a sufficient security against crazing may be attained when in any manner intervening adjusting layers are developed between the body and the glaze. Likewise the elasticity of the glaze plays a rôle. A test method must therefore be found which is founded upon the actual conditions.

With unsimilarity of the coefficients of expansion, the glaze is

found to exist in a strained condition which ultimately results in rupture. This occurs the earlier, the oftener the object is subjected to temperature alternations, that is, when it has been alternately released from tension and again been brought into tension, and the higher and more sudden these temperature alternations are.

THE METHOD OF TESTING

Upon these observed facts depends the following method of testing: the object to be tested is heated to a certain temperature, and then is suddenly reduced to room temperature by plunging into water. This procedure is continued with successive elevation of temperature each time, until a rupture occurs. That which occurs slowly and in small degree in actual conditions of use, is here intensified and produced in a very short time. This method of testing is independent of any particular theory of crazing, since it reproduces simply the actual working conditions. Since, as the result of this test, an earlier cooling of the glaze than of the body occurs, the objection may be made that the glaze must necessarily rupture even though the glaze and body have like coefficients of expansion and contraction. However, in such a case the test will indicate a greater ability to withstand strain than in cases where the same glaze is used with a body of smaller coefficient of expansion. The method gives relative results in every case and it is very important to make the observation that the crazing of a glaze by "quenching" does not necessarily allow us to conclude that it would do likewise under conditions of use.

For carrying out the test, I employ a drying oven which is heated by electric current with the greatest possible uniformity by means of wire winding. It has been found practical to go to 120°C. on the first heating; and then, in case no crazing of the glaze occurs, the testing temperature is raised 10° each time. The heating must be accomplished gradually in order that the piece actually acquires the temperature which the thermometer indicates in the center of the oven.

I introduced this test two and one-half years ago, and in the lapse of this time have studied a great number of pieces which were not tested but which were carried through the complete process of

manufacture at the same time as the pieces which were tested. In this manner the results of the test could be compared with the actual behavior (of untreated pieces). During the same time, the commercial output of the factory was controlled, and the conclusions which could be drawn from the results of this control agreed with the actual behavior.

As a result of this, the following condensed statements may be made. With a quenching temperature limit of 120°C., crazing begins in a few days. With quenching results at higher temperatures, the durability of the glaze increases, until at 150°C. a period of approximately three to four months is necessary. At 160°C. the majority of the pieces were not crazed after fifteen months, although in one case a rupture occurred after eight months. At 170° and 180° with one exception, durability continued during the entire period of observation of two and one-half years. In ware that stood a temperature of 190° and above, not a rupture has occurred up to the present time. One would designate 200°C. as certainly a safe minimum for a durable product.

That entirely sharp results were not obtained is explained by the fact that the temperature is not the same in all parts. Then also the thickness of the glaze necessarily plays a rôle, since a thicker glaze ruptures more easily than a thin. Investigations concerning this point have shown that variations up to 20° in the quenching temperatures are possible.

The possibility of so regulating the test that the temperature after each test was not elevated but was always brought back to 120° was then investigated. The following table shows the results:

DESIGNATION OF BODY	TEMPERATURE OF FAILURE	REPETITION OF THE TEST AT 120°
M. 43.....	Up to 210° not crazed	After 15 tests not crazed
G. M. 118 ..	190°	After 15 tests not crazed
G. M. 12 ...	150°	After 5 tests not crazed
M. L.....	120–130°	After 3 tests not crazed

By this method a gradation was obtained similar to that by quenching after elevation of temperature; but since the latter treatment is accomplished more quickly, it is naturally to be given

preference. It may be possible in cases where the coefficient of expansion of body and glaze are nearly the same that a rupture occurs when a high "quenching" temperature is used, but if a lower quenching temperature were used the glaze might remain sound. Moreover, the elasticity of the glaze plays an important rôle, and it may be that the elasticity is so small that when the piece is subjected to quenching, in which the glaze always contracts faster than the body, crazing occurs at a low temperature. In such cases, however, it can be said of the glaze, that it is little suited for making a durable product. If this case appears in the testing of a body, another glaze must be selected which has stood higher temperatures when used on other bodies.

CONCLUSION

In general, the process offers a proved, quick, and reliable method of obtaining enlightment, heretofore entirely lacking in pottery manufacture, concerning the question of development of crazing in glazes. Concerning the results of a systematic investigation of the relations between body composition and the development of crazing in glazes, and concerning the possibility of bringing about reliability in that way, I will report in a later communication.

SILICATE ENGINEERING OR CERAMIC ENGINEERING, WHICH?

BY SAMUEL GEIJSBEEK, PORTLAND, ORE.

In a report of the director of the Oregon state bureau of mines to the twenty-seventh regular assembly of the Oregon legislature, we find the following statement: "Among the important geological products of the state which should be rapidly developed, the Ceramic industry is one which in our opinion should receive state attention. In the modern sense of the word this term is now generally applied to the technology of the earthy and non-metallic minerals and hence embraces the so-called silicate industries which deal with the manufacture of all kinds of clay products, glass, cement, lime, plaster, etc." This statement has produced a great number of objections, not only from the clay people but also from the cement and quarry men, as to the application of the term "ceramic industry" to something which has never anything to do with ceramics. Therefore to include with this term all the earthy and non-metallic mineral industries is evidently something with which the general public is not in favor, and which will confuse each industry by itself. For instance, a lime burner or lime manufacturer would feel embarrassed if his product would be called "ceramic ware," and a cement man would certainly find it a good joke on the clay people—whom he does not love very particularly anyhow—if his line of cement products would be classified as "crude ceramic ware" in comparison with fine china or pottery manufacture, which would then be classified as "fine ceramic ware."

If the scientific people have been advancing such terms, they have certainly done so without consulting the practical man, who begins now to feel that his original trade name is in danger of being taken over by some of his competitors.

In order to obtain a definition of the word "ceramics," we have obtained from Professor Orton the following: "Ceramic engineering is the engineering and technology of the silicate industries, especially the clay, glass, cement and mortar material industries. Employing the words ceramic engineering rather than 'ceramics' will eliminate the old idea of ceramics, as the word engineering

added to it will automatically carry a meaning which removes the idea of the art phase of the subject, and brings in the technical."

Professor Bleininger states that "the subject of ceramics as taught in our schools includes the manufacture of clay products, glass, cement, lime, etc., and it is becoming customary even in Europe to collect the various rock product industries under this one general heading. The use of the word 'ceramics' in this connection is undoubtedly bad practice, and this point is freely conceded. I would suggest the term 'silicate technology.' "

Personally, we do not fully agree with these definitions of the term ceramics, for if ceramics is one thing, it is certain that the engineering of ceramics or ceramic engineering cannot be something else. Even if the addition of the word engineering will take the art idea away, the finished products, such as cast-cement garden vases and highly ornamented or fancy scroll work on cement buildings, would never be in an art sense called ceramics. As a clayman, it is strictly against my views to have the rock producing industries classified with ceramics, and we think it will be well to leave the word "ceramics" belong to the definition in which it has been classified for centuries. You cannot change a name without sanction from somebody; and if this matter is properly discussed, we think that the application of the term Silicate Engineering will far better apply itself to the rock producing, also glass and clay industries, as being properly the silicate industries than to change them all to ceramic industries.

The change of the name to "silicate industries" will at once convey to either layman or technical men the meaning of such industries, and do away with any connection with either art ceramics or technical ceramics. It will also assist the genuine ceramic people to maintain their term as applied to the art of this industry.

NOTE OF STANDARD TESTING SIEVES

BY C. H. KERR, TARENTUM, PA.

Need of Standard Sieves. Most of the sieve test records are hopelessly confusing. Usually comparisons are not possible because the records do not include data concerning the sieves used. When such data are given it is usually necessary to plot cumulative curves showing the relation between residues and sizes of hole before comparisons can be made. It has been apparent to everyone that standardization of testing sieves was imperative but nevertheless no widely used standards have been adopted. Many minor points might be given, which should be included in specifications for sieves to be used in particular lines of work, but for any purpose whatever testing sieves must possess the following requisites.

1. They must be practical sieves, convenient in use and free from unnecessary clogging, etc.

2. The standards must be systematically arranged to make possible a regular plotting of sieve test curves.

3. The sieves must be practical from the sieve manufacturer's standpoint to enable accurate duplication of the work.

Standards Proposed. Many standard sieves[1] have been proposed by different individuals and organizations. No attempt is made here to give a complete history of this standardization work but some points of development will be noted.

The Institution of Mines and Metallurgy[2] of Great Britain recommended the "I.M.M. Standard Laboratory Screens" based upon a constant relation of 25 percent screening area (that is size of wire equals size of hole) and also upon a constant reduction of 25 percent in size of hole between consecutive numbers. This 25 percent screening area specification means that in the coarser screens the wire is exceedingly coarse. The results obtained with these standard screens have shown that in the coarser numbers the

[1] For a complete bibliography of sieves see Richards, *Ore Dressing*, Vol. 1, p. 336–86; Vol. 3, p. 1361–66; Vol. 4, p. 2018–19. The double Rittinger ratio (basing changes in size of hole on $\sqrt[4]{2}$) was recommended by Hutchinson, *Eng. and Min. Jrl.* 80: 213 (1905). The "law of cubes" sieves are discussed by, Dietz and Keedy, *Met. and Chem. Eng.* 9: 577–80 and Rice, *idem.* 9: 627.

[2] *Electrochem and Met. Ind.* 5: 512; 6: 28.

wire is much too coarse to be at all practical even in laboratory work. They show excessive clogging and also a tendency to variation in results because with this very coarse wire different sizes are allowed to pass through, varying with the direction of passage through the sieve. Many tests were made to show these objections. The following illustrate the excessive clogging, the sieve test being made on ground fire clay grog.

14–mesh screen gave 8.0 percent of the residue clogged in the sieve.

20–mesh screen gave 1.8 percent of the residue clogged in the sieve.

In comparison with these figures a fine wire screen as described later shows from about 0.1 percent to about 0.3 per cent clogged in the sieve. These standard sieves are therefore unsatisfactory. With the size of wire equal to the size of hole the above objection disappears in the sieves finer than about 30-mesh.

Committee "H" on Road Materials of the American Society for Testing Materials[3] recommended a set of standard sieves for the testing of road materials. The specifications are given below.

MESH	DIAMETER OF WIRE	SIZE OF HOLE
	inches	*inches*
10	0.027	0.073
20	0.0165	0.0335
30	0.01375	0.01958
40	0.01025	0.01475
50	0.009	0.011
80	0.00575	0.00675
100	0.0045	0.0055
200	0.00235	0.00265

From the standpoint of convenience in use these sieves give satisfaction; but the series is not complete, and the successive steps are not arranged in a systematic order to best facilitate recording and comparing the data.

The Bureau of Standards at Washington has taken up the question of standard testing sieves and has recommended a series of sieves based upon a 200-mesh sieve (size of hole 0.0029 in.) and

[3] *Proc. Am. Soc. Testing Materials*, Vol. 9, p. 21 (1909). See also Bulletin No. 38 Office Public Roads.

increasing the consecutive members by the $\sqrt{2}$ or 0.414. This is the well-known Rittinger ratio.[4] This basic ratio is an excellent one for the reasons noted below. Following this scheme a very satisfactory series of sieves can be developed, and this has now been accomplished.

New Standard Screens. Based upon the Rittinger ratio the W. S. Tyler Company of Cleveland, Ohio, has developed a standard screen scale which meets our needs. Starting with the 200-mesh sieve with size hole equal to 0.0029 in., each coarser sieve is 0.414 larger in size of hole than the next finer number, and for each size of hole a suitable size of wire is chosen thus establishing the mesh. As now arranged the sieves are as follows:

MESH	SIZE OF WIRE	SIZE OF HOLE
	inches	*inches*
	0.149	1.050
	0.135	0.742
	0.105	0.525
	0.092	0.371
3	0.070	0.263
4	0.065	0.185
6	0.036	0.131
8	0.032	0.093
10	0.035	0.065
14	0.025	0.046
20	0.0172	0.0328
28	0.0125	0.0232
35	0.0122	0.0164
48	0.0092	0.0116
65	0.0072	0.0082
100	0.0042	0.0058
150	0.0026	0.0041
200	0.0021	0.0029

The advantages of this series of sieves may be summarized as follows.

1. The sieves are practical working sieves and can be obtained without being made on special order.

2. In the complete series of sieves the size of hole increases according to the Rittinger ratio of 0.414 to 1. By omitting in regu-

[4] Richards, *Ore Dressing*, Vol. 1, p. 366.

lar order, one, two or three sieves, the size of hole may be increased by ratios of 2 to 1, 3 to 1 (about), or 4 to 1 respectively.

3. For direct cumulative plotting this ratio of $\sqrt{2}$ makes a very convenient curve.

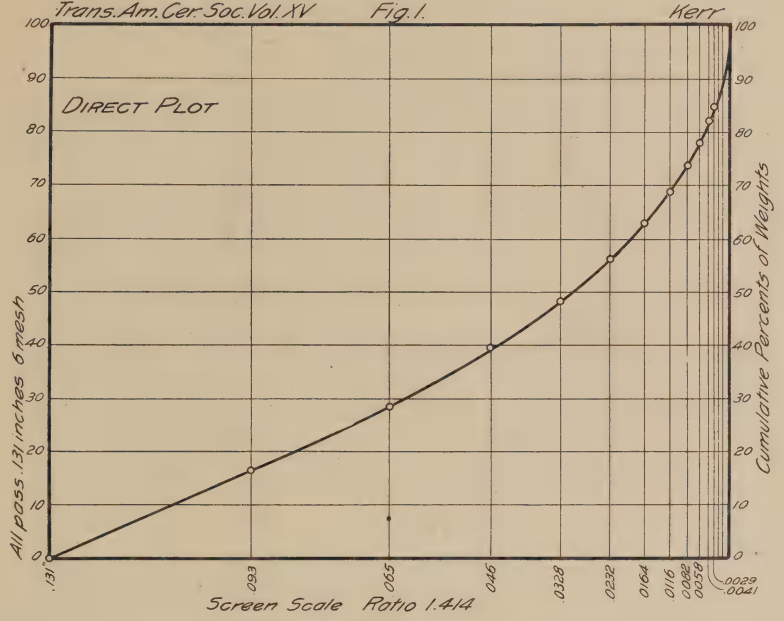
4. The logarithmic plot for this ratio is very simple. Logarithmic plotting is usually more instructive than direct cumulative plotting because equal distances along the horizontal scale represent equal ratios while in direct cumulative plotting they represent equal intervals of size. Therefore in logarithmic plotting the coarse end of the curve is compressed, and the fine end expanded as compared with the direct cumulative plot.

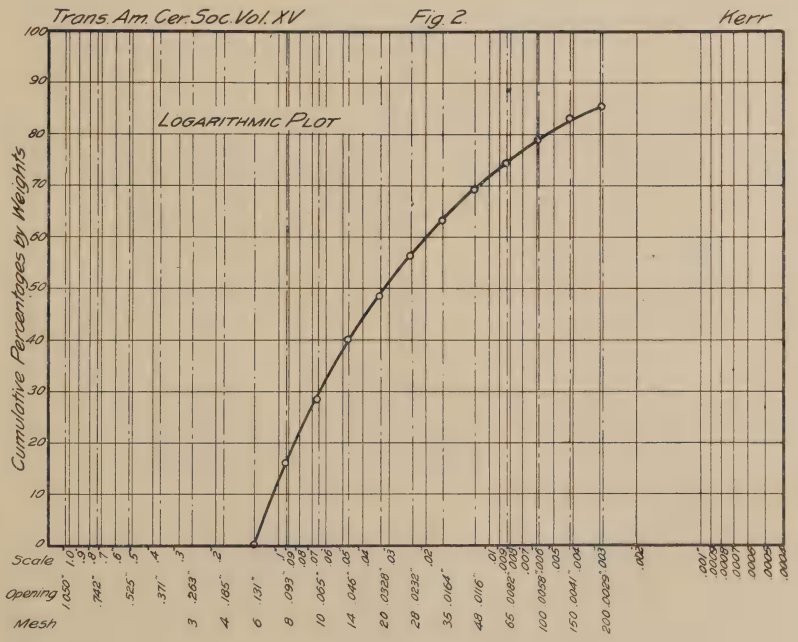
To illustrate the recording and plotting of sieve test data obtained with these sieves an example is given and the curves are shown.

GROUND FIRE CLAY GROG

SIEVE			PER CENT RESIDUE	CUMULATIVE PERCENTS
Hole	Wire	Mesh		
inches	*inches*			
1.050	0.149			
0.742	0.135			
0.525	0.105			
0.371	0.092			
0.263	0.070	3		
0.185	0.065	4		
0.131	0.036	6	All pass	
0.093	0.032	8	16.1	16.1
0.065	0.035	10	12.2	28.3
0.046	0.025	14	11.5	39.8
0.0328	0.0172	20	8.4	48.2
0.0232	0.0125	28	7.9	56.1
0.0164	0.0122	35	6.9	63.0
0.0116	0.0092	48	5.8	68.8
0.0082	0.0072	65	5.1	73.9
0.0058	0.0042	100	4.4	78.3
0.0041	0.0026	150	4.0	82.3
0.0029	0.0021	200	2.7	85.0
0.0029	0.0021	200	15.0	100.0

From these data the direct cumulative plot and the logarithmic cumulative plot are drawn (see Figs. 1 and 2).


Trans. Am. Cer. Soc. Vol. XV
Fig. 1.
Kerr
DIRECT PLOT
All pass .131 inches 6 mesh
Cumulative Percents of Weights
Screen Scale Ratio 1.414
.131
.093
.065
.046
.0328
.0232
.0164
.0116
.0082
.0058
.0029
.0041


Trans. Am. Cer. Soc. Vol. XV
Fig. 2.
Kerr
LOGARITHMIC PLOT
Cumulative Percentages by Weights
Scale
Opening
Mesh

DISCUSSION

Mr. Bleininger: I would like to call your attention to an instrument for estimating the value of sieves. You can tell at a glance of half minute or less whether or not your sieve is off and how much it is off. I thought perhaps you would like to see it to-morrow and should be glad if you'd call my attention to it.

Mr. Kerr: I might add that if anyone is especially interested in this work, there are a number of things at the Bureau of Standards which they would be very glad to show.

Prof. Parmelee: What is the shape of the larger sized holes.

Mr. Kerr: All square; they are all woven wire screens. The largest size has a hole 0.050 inches in diameter, but in the testing work we are interested chiefly in the finer sieves.

Prof. Parmelee: But of course the circular opening has a distinct advantage over the square opening.

Mr. Kerr: In the larger sizes that is undoubtedly true. If we used the very coarse sieves very extensively we would undoubtedly adopt the round hole. I might ask if it is possible for the Society to take action in any way to accomplish standardization along such lines as this? It is something, it seems to me, strictly within the functions of the Society, and any action along that line would be a very great help to all people in ceramic work.

Mr. Watts: It seems to me that might be taken up but I am afraid it would be rather unwise to undertake a discussion of it at this time. That might be a good thing to bring up at some future meeting or at some future time.

EXAMINATION OF COMMERCIAL SPAR

BY WILLIAM J. McCAUGHEY

In the years from 1903 to 1908, there was produced in the United States an annual average of 59,000 tons of feldspar with a valuation of $380,000. Of this, the major part was consumed in the ceramic industries, and this material was sold to the manufacturer on a guarantee of geographical location, which may or may not be satisfactory. The value of the spar represents, however, but a small part of the value of the finished material in the manufacture of which the feldspar is used.

The present paper is an attempt to apply a rapid method for the examination of commercial spar and offers observations on the mineral composition of spars noted in the course of such examinations. The basis of this examination consists in the identification of the minerals composing the spar and their approximate quantitative determination.

The feldspars are aluminosilicates of potash, soda and lime. These minerals are the most common of rock forming minerals and are found to some extent in almost all rocks and soils and particularly are they abundant in igneous rocks. Professor Clarke of the U. S. Geological Survey estimates they make up 65 percent of the crust of the earth. Commonly these minerals are associated in igneous rocks with iron-magnesium minerals, which prohibit their use commercially.

The commercial deposits of spar are found in so-called pegmatite dikes which are igneous in origin and appear to be segregations produced in the cooling of igneous rocks. It has been shown by Vogt that the pegmatities are likely eutectic mixtures of quartz and spar in which the proportion of spar to quartz is about 3 to 1. The pegmatites may be looked upon as exceedingly coarse grained and rather pure granites, consisting mostly of feldspar and quartz in which the percentage of accessory minerals present is rather low.

Soda spar or albite is the one end member of a series of isomorphous mixtures in which the albite molecule is partly replaced by the pure lime feldspar anorthite. The soda spar of commerce is

not pure albite, which is rather a rare mineral, but an albite containing varying amounts of the anorthite molecule. The presence of several percents of calcium oxide should not necessarily be regarded as an impurity.

The potash feldspars consist of the two minerals, orthoclase and microcline, and these, when unaltered and pure, have identical composition. They have been the subject of considerable mineralogical research and speculation, which seem to indicate that they are identical, orthoclase being an exceedingly finely twinned microcline. It is difficult to reconcile this statement, however, with the remarkable difference in the ability of these two minerals to withstand chemical weathering. Orthoclase is the common potash feldspar occurring in igneous rocks. Where these rocks have been subject to regional metamorphism, the orthoclase has been altered to form the triclinic potash feldspar microcline.

The pegmatite dikes of the eastern United States generally occur in the very old rocks (pre-Cambrian) and have been subjected to the forces of metamorphism which have been instrumental in building mountains. It is likely that the result of these forces has been to change in a large measure the potash feldspar, orthoclase into microcline. As a matter of fact the potash feldspar commonly present in these dikes is microcline. Several years ago the author endeavored to obtain a supply of orthoclase for experimental purposes and sent to several mineral collectors and to the United States National Museum. Almost all of the samples submitted were microcline and the experimental work had to be abandoned on account of the unsuccessful search for orthoclase in quantity.

From the examination of many hundred samples of soil from the United States and of other samples collected from different parts of the world, it has been an invariable experience to find microcline to withstand chemical alteration very well. Orthoclase, on the other hand, seems to weather much more readily. In point of fact, in soils examined from the coastal plains, we find microcline associated with such insoluble minerals as zircon, tourmaline and hornblende. Even in such samples microcline invariably appears in grains quite free from chemical disintegration. Orthoclase on the other hand is one of the first of the silicates to alter in the ordinary disintegration of rocks. This difference in the chemical disin-

tegration of these two minerals is quite noticeable in commercial samples of spar examined.

The soda spar albite is sometimes found intimately associated with the potash spars existing as an intergrowth of albite in orthoclase or microcline, known as perthite. In the ordinary commercial spars, this intergrowth is sometimes quite coarse. In the smaller crystals of feldspars occurring in rocks, this perthitic intergrowth is very fine and is then known as microperthite. Brögger in his examination of perthites of Norway assumes that in some of the so-called soda orthoclases this intergrowth is so fine that it cannot be revealed with the microscope. These he calls cryptoperthites.

The commercial feldspars are the soda spar and the potash feldspars, orthoclase and microcline, differing in crystal form and certain physical properties, and in the ability to withstand chemical disintegration. The soda spar albite occurs either separately as a commercial spar or associated with orthoclase and microcline as perthite. Albite possesses a greater degree of resistance to chemical disintegration than does orthoclase, and in the samples of commercial soda spar little or no signs of chemical alteration appeared.

The examination of feldspars is carried out with a microscope fitted with a polarizing device. The latter is not entirely necessary but makes examination more satisfactory. The method depends upon the identification of orthoclase, microcline, albite and quartz by differences in the indices of refraction of these substances. The distinction between orthoclase and microcline must be made in polarized light.

The feldspar is crushed until it passes a 100-mesh sieve. About 3 mgms. of this sample is taken on a point of a knife and placed on a microscope slide. Beside this is placed a drop of clove oil, the two are mixed by the use of an edge of a cover glass and the latter is placed on top. Clove oil has an index of refraction (1.527) which is intermediate between the indices of the potash spars and albite. The index of refraction of the clove oil varies somewhat. The index may be lowered by adding cedar oil or raised by adding cinnamon oil.

It is only necessary then to use a microscopic method which will indicate these differences to identify the minerals. There are two such methods.

SCHROEDER VAN DER KOLK METHOD

This method is quite sensitive but requires the proper adjustment of a condensing lens, otherwise the reaction may be the reverse of that described. It is better to try it out first on known minerals and oils. The method consists in comparing the indices of the minerals with an imbedding medium in this case clove oil.

The finger partly shades the reflecting mirror or the polarizing case throwing a shadow partly on the field. Near the boundary of this shadow the following may take place:

1. A line of light on the edge of the mineral toward the shadow.
2. A line of light on the edge of the mineral away from the shadow.
3. The grain is colored blue on the edge away from the shadow and red on the edge toward the shadow.

In the first case the index of the mineral is higher than the oil. In the second case the index of the mineral is lower than that of the oil. The third case, the index of the mineral is equal to that of the oil.

BECKE METHOD

In this method the grains are sharply focused, the condensing lens removed, and the field partly shaded. As the tube of the microscope is elevated (fine adjustment), a line of light appears at the edge of the grain and enters the medium with the higher index. In the case cited, this line, Becke's line, enters the albite particles; in the case of the orthoclase and microcline particles, the line of light goes from the edge of the grain into the oil; i.e., the index of the potash spars are less than the oil and the soda spar greater than the oil.

The approximate percentage of the mixture is then recorded by taking the average of a series of counts, in no case, however, using sections carrying less than 75 grains. Albite may be determined directly, if the microscope is provided with a polarizing equipment, or it may be determined by difference in the following way. An oil whose index equals 1.545 (ordinary ray of quartz) is prepared and the percentage of quartz and minerals having higher indices (muscovite, garnet, tourmaline) is determined using the Schroeder Vander Kolk reaction. The percentage composition of albite is determined by difference.

Feldspar particles on account of the perfection of two pinacoid cleavages appear in rather tabular shapes with a pair of more or less parallel edges. These parallel edges are sometimes extended, giving the particle an elongated aspect. The basal cleavage (001) is the most highly developed and generally forms the base of the tabular fragment. The pair of parallel edges mark the trace of the other cleavage, the side pinacoid (010). Occasional grains, however, are tabular in the direction of the side pinacoid (010) and the parallel edges of this fragment are the traces of the base cleavage (001).

The appearance of these minerals in polarized light between crossed nicols furnishes an invaluable means of distinguishing them. The angle of extinction measured from the trace of these cleavages are characteristic of the feldspars and are the principal means of identification. In the accompanying table, appear the optical

TABLE I.—OPTICAL PROPERTIES OF THE FELDSPARS

	EXTINCTION ANGLE		INDICES			OPTICAL CHARACTER
	On 001	On 010	α	β	γ	
Orthoclase.....	0	6°	1.518	1.522	1.524	−
Microcline.....	15°30′	6°	1.518	1.522	1.524	−
Albite.....	4°	20°	1.529	1.533	1.539	+
Oligoclase.....	2°	4°	1.539	1.543	1.546	−

characteristics of the three important commercial spars on the two principal cleavage faces produced by breaking in the mortar. Therefore it is advisable to break the specimens and not to grind them.

The interference color (birefringence) of the feldspars under the microscope between crossed nicols is rather distinctive. Orthoclase and microcline yield pale colors, white or yellow, depending upon the thickness of the grain. Albite, however, on the basal pinacoid and quartz have a much higher color (birefringence), red and blue, which rather easily distinguishes them from the potash feldspars. Albite is readily distinguished from quartz by the absence of cleavage in the latter, which furnishes grains with irregular outline. Attention must be directed at this time, however, to a

variety of quartz, known as amethyst. Amethyst is a polysynthetically twinned quartz, and is sometimes found with pegmatite. In breaking down amethyst in a mortar, the mineral separates along these composition planes and yields tabular fragments not unlike the feldspars. These two are distinguished by their indices.

Upon observation in polarized light, it is seen that the feldspars often show twinning. The twinning is seen as alternate series of bands which have homogeneous extinction. Orthoclase does not show polysynthetic twinning, occasionally it shows two alternate broad bands (Carlsbad); but these are rarely found in commercial spar. Microcline is almost invariably twinned polysynthetically. On the base (001) twinning gives the appearance of a plaid or lattice work. These twins have an angle of 30° between positions of extinction for the adjacent twinning bands. On the side pinacoid of microcline, only one series of twinning bands are present and these are nearly at right angles to the trace of the basal cleavage. The angle included between the extinction positions of the two sets of twins equals 12°—15°.

Albite on the basal cleavage face shows polysynthetic twininng. The angle included between the extinction positions of the two sets of twins varies from 8° to 0° with variation in calcium content. In the large crystals of feldspar occurring in pegmatites, these polysynthetic bands are often quite broad, so that in the preliminary preparation these are severed and the albite appears under the microscope as untwinned, due to the coarseness of the crystallization and twinning. In commercial spar, this is quite common. The high birefringence of albite on the basal cleavage distinguishes it readily from orthoclase and when its extinction equals 0° the different indices of refraction serve the same purpose. Twinning may be absent in the microcline fragments, sometimes due to the coarseness of crystallization. In all these cases, it is best to identify the mineral by its indices of refraction and the extinction angles measured on each cleavage face from the trace of the other cleavage.

Minerals commonly associated with the feldspars are quartz muscovite, garnet, tourmaline and beryl. Muscovite is recognized by its high index and low interference colors, gray to pale white, and a tendency to fray at the edges and turn up, and this furnishes higher interference colors, at the edges. Garnet is generally irreg-

ular in outline (no cleavage), of a faint pink color, very high index of refraction (high relief) and does not transmit light between crossed nicols. Tourmaline may be green, pink, or dark brown to black in color, has high index, and high interference color. The darker varieties show a marked absorption of one of the rays. Beryl is quite similar to quartz, has a somewhat higher index, lacks cleavage, and has the same interference color between crossed nicols. It is practically colorless under the microscope.

In the regular course of examination of spar the accessory numerals and the felspars, after a short experience, are recognized on sight and their quantitative composition readily determined.

SHOP NOTES

BY HERFORD HOPE, NEW BRIGHTON, PA.

INTRODUCTION

Although the following notes, somewhat disconnected as they are, may treat of matters which are familiar and even commonplace to the great majority of potters; yet there is always the possibility of a hint being dropped that may prove useful to some one. With that point in view are mentioned a few of the methods used in the clay shop of which the writer is at present in charge, that of the Mayer China Company, of Beaver Falls, Pennsylvania.

BALANCE SHEET SHOWING MOULDS ON HAND AT ANY TIME

In any pottery making a variety of shapes and sizes, and particularly where facilities for drying moulds are not of the best, it is important and even essential to know what moulds are already made and ready for use, so that, on the one hand, one may know that when a round of moulds is ready to replace it, and also that there may be no duplication of orders, a matter not easy to avoid without accurate knowledge of the stock on hand. While it is not good business policy to tie up money unnecessarily in moulds, there can be no doubt that the making of moulds from four to six weeks in advance of requirements permits a slow and natural drying which undoubtedly improves their wearing qualities. If this course is pursued, a considerable and varied stock of moulds is unavoidable.

To keep an accurate account of these is very little trouble if care be taken in making the entries. The mouldmaker is provided with a list of moulds to be made, this being added to by the foreman from time to time. The following facsimiles will show how the sheets are used.

TABLE I.—NEW MOULDS TO BE MADE

Article	*Dozen Wanted*
Plates, 5 ft. Thick	40
Plates, 3 ft. R. E.	10

At the end of each year, stock is taken of the new moulds outside of the clay shop, and they are entered on sheets ruled for the purpose (see Table II), each item in its proper place, with plenty of space provided for entering new moulds throughout the year. As each item on the order sheet is completed (see Table I) it is crossed out and at once entered on the Record Sheet (Table II) as shown. Before a new round of moulds can be brought into the clay shop, an order from the foreman to the mouldmaker must first be obtained; and on completing the order, the mouldmaker crosses off the item on the Order Sheet, that particular round of moulds having passed out of his hands. By this method the exact condition of the mould stock may be ascertained any day of the year.

TABLE II.—RECORD OF NEW MOLDS ON HAND

DATE MADE	MADE BY	ARTICLE	DOZEN
8/19/12	G. K.	Tea Saucers, Hub	10
8/19/12	G. K.	Tea Saucers, Newton	15

SYSTEM FOR KEEPING TRACK OF WARE WANTED QUICKLY IN BISCUIT

The following table illustrates the system used.

TABLE III.—WARE WANTED SPECIALLY FOR BISCUIT KILN NO. 1, TO GO IN FEBRUARY 5, 1913

ARTICLE	LEFT OUT OF LAST KILN	CARRIED OUT FEBRUARY				TOTAL	LEFT OUT OF KILN	WARE IN KILN
		2	3	4	5			
Coffee Cups, Chicago	20	x	50	25	x	95	x	95
Plates, 7-deep Thick	50	x	x	x	x	50	25	25
Dishes, 5 R. E	10	x	x	x	10	20	20	x

The quantity of any item wanted is counted in the greenroom and entered in the first column to the left. The amount carried into the greenroom each day is entered in the next column, and when the kiln has been placed, the total number of dozens brought into the greenroom up till that time is placed in the column assigned

for those figures. The total number of dozens left out of the kiln go in the next column, the final and right hand column being the difference between the other two, or the ware gone in the kiln. For the following kiln, the amount of ware left out of the last one forms the left hand column again. The keeping of this record materially assists the biscuit warehouseman as he knows just how much there is of the items he requires in the kilns yet undrawn. It will be obvious, of course, that this system covers only such items as are wanted quickly, as it would be quite impractical to include even the majority of articles manufactured.

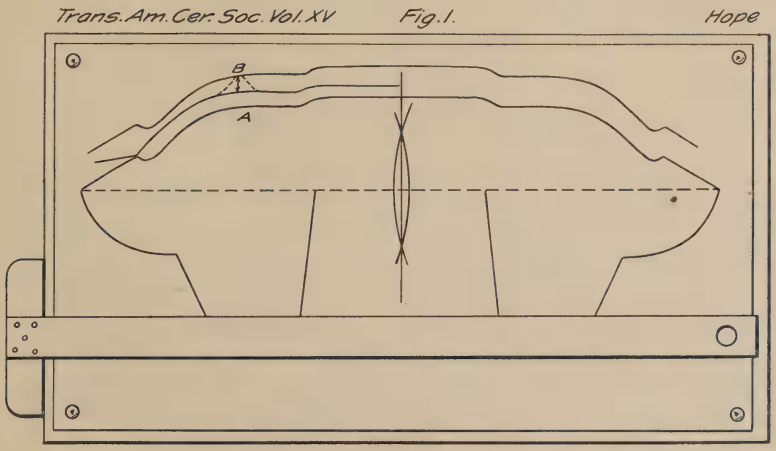
DESIGNING AND MAKING PROFILES

In all classes of ware, except, perhaps, the very thickest and the most crude, a knowledge of the exact thickness in all parts of given pieces is most necessary, it being evident that the thinner the ware, the greater the care that must be exercised in this regard. It is not the purpose of this note to enter into a discussion of the objects in making certain parts of a piece either thicker or thinner, but rather to explain the method used in making the profiles or templates, particularly as regards getting the feet of flat ware the proper height so that, on the one hand, there may be a fair clearance between the plates, or saucers as the case may be, when they are placed in bungs, and, on the other hand, that the feet may not be made too high and thus cause loss of space in the kiln.

A section is made through the center of a mould, and if it has a scalloped edge, through the middle of the deepest scallop. A T-square and drawing board should be used, the head of the former being placed against the left side of the latter, and the lower part of the mould section resting on the upper edge of the T-square blade. This will ensure parallelism of any outlines drawn from the plaster section, provided care is taken that the latter moves in an exactly vertical direction. After drawing such an outline (as in Fig. I) the profile is sketched at the proper distance to allow for the required thickness of the piece, but while the position of the foot is indicated, its exact height is at present unknown. If the mould section is replaced so as to exactly cover the first outline, the T-square blade moved up to it, and both carefully moved

upward until there is secured what would be considered a proper clearance between the pieces, and a second outline made, as at *b* in the diagram, it is obvious that the proper height for the foot is the space between these two outlines at the point previously decided upon.

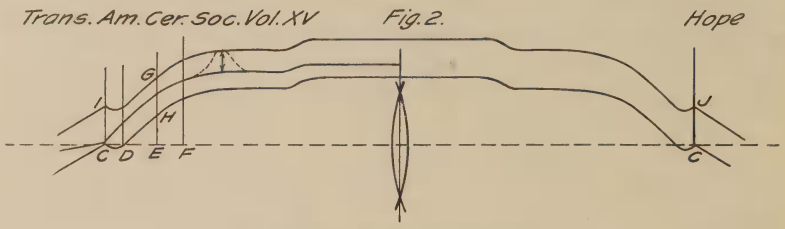
In case no T-square or drawing board is available, the following method may be adopted. After making the mould section and marking its center (which should be done in either case) outline it on a piece of paper, and draw a straight line through the highest point of the welt on either side (marked *c* in Fig. II).



Sketch the profile at the required thickness, indicating position of the foot as before. Erect perpendiculars at points *c, c,* and also at several points along the line of the profile where the piece appears to show the greatest vertical thickness, as at *d*, *e*, or *f*. Space this thickness with a pair of dividers, or otherwise, at the same time adding what would be considered a proper clearance between the two pieces, as at *g*. From points *c, c,* mark off on the perpendiculars *ci* and *cj* equal to *gh*. Again place the plaster section on the paper, its outline touching points *i, g,* and *j*, and the height of the foot will be indicated as before. This last method of profiling takes slightly longer than the other; but both are extremely simple, and if ordinary judgement is used in determin-

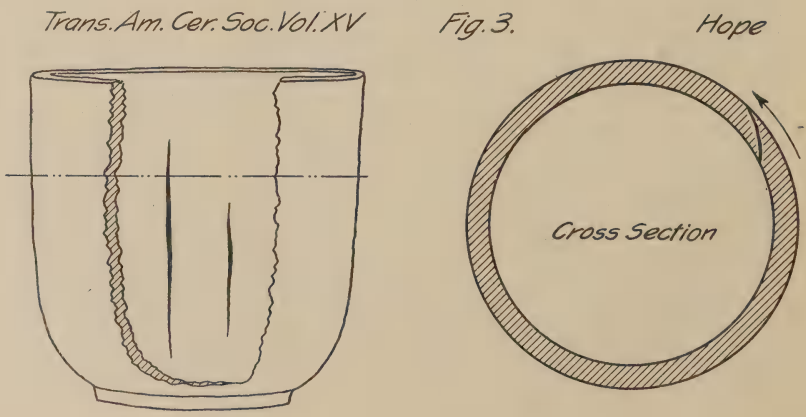
ing the proper clearance between the pieces, the jigger tool can be filed up and any quantity of ware made without any preliminary trials.

After the correct outline has been made on paper, it should be cut out and traced on sheet zinc, the latter material being very suitable for the permanent profiles.



LOSS IN THICK CUPS AND MUGS

Loss of ware in the green state furnishes some of the most perplexing problems which a potter has to solve, and this is true in the manufacture of vitrified china as much as in any other branch of ceramics. No other type of clayshop loss has given the writer more trouble than that occuring on the inside of thick, straight sided, hollow-ware such as cups and mugs, making its appearance as a crack, usually long, almost always vertical, and beginning to be evident when the ware is about half dry, before it has begun to turn white. By those who are familiar with it, Figure 3 will be easily recognized as typical of this kind of crack.



Without doubt a number of different factors affect the cracking in greater or less degree, some of these being the following:

1. The Body
   - (a) Composition
   - (b) Consistency as used
   - (c) Faults due to pugging
2. The Speed of Jigger
3. Jiggering
   - (a) Method of making bat or ball
   - (b) Pulling up bat or ball
   - (c) Putting in tool and finishing piece
4. Drying
   - Conditions of drying
5. Jigger Tool
   - Thickness of.

It is most likely that still other factors, such, for instance, as the difference between hard and soft moulds, affect the results; but as the writer can offer no theory to account for the effect of such, he will leave the discussion of these points to others.

The Body. *a.* Composition. It is generally conceded that increasing ball clay in a pottery body will decrease cracking in the green state, but in the case of this particular type of crack, the writer believes that a shorter body has less tendency to crack than one more plastic. The reason for which opinion will appear later.

b. Consistency. Clay of a medium consistency—that which is known to potters as goood order clay, a somewhat indefinite term it must be admitted—is best; for if too soft, the contraction is too great, and if too hard, the tool, in forcing its way through, is apt to twist and stress the clay.

c. Pugging. This is naturally of very great importance, since such defects as blisters or hard lumps in the clay will of themselves start cracks.

The Speed of the Jigger. There can be no doubt that excessive speed will have a tendency to cause cracking, owing to the sudden twisting strain on the clay as the tool touches it. We consider 300 to 325 r.p.m. sufficient speed for any of the straight

cups to which reference has been made; and for the very thickest, a still slower speed should be maintained. A very slow speed would tend to drag the clay instead of cutting off cleanly, so that it should be kept within proper limits.

Jiggering. *a.* Making the Bat or Ball. In the majority of cases, it is found that a bat or liner shaped over a wooden "chummer" gives better results than a ball, probably owing to the fact that the shape of the ware to be made is already approximated and less work remains to be done by the tool. In either case great care should be taken that the clay is cut off cleanly and that no air blisters are introduced.

b. Pulling up the Bat or Ball. The clay should always be run up to the top of the mould by hand before the tool is introduced, this again lessening the work of the jigger tool. Care should be taken to accomplish this running up process without leaving deep furrows or ridges caused by the fingers, since the tops of these ridges might be turned over and air or water enclosed, in which case cracking would be likely to result.

c. Putting in Tool and Finishing Piece. A great deal of the final success in making any kind of ware on the jigger is due to the care with which it is lubricated with water while under the tool, and the water distributed over the surface. The best results are obtained only when the tool leaves the piece shining all over, but with no free water or slurry on the surface. If too much water is used in making cups and similar ware, it is likely to settle at the bottom and crack them there, this being quite a different crack from that under discussion, but not any more satisfactory in the end, except that the cause is so easily discovered and removed. If the piece is finished too dry, its surface will be rough and open, and that condition naturally predisposes it to crack in drying. Aside from the question of the proper amount of water to be used, the rate at which the tool is pushed into the clay, the length of time it is held there, and the manner in which the pressure is released and the tool removed, all have their influence upon the result.

Drying. It is quite safe to say that the more slowly any clay ware is dried, the less liable it is to crack; but as considerations of time and space enter into the day's work to a large extent, a

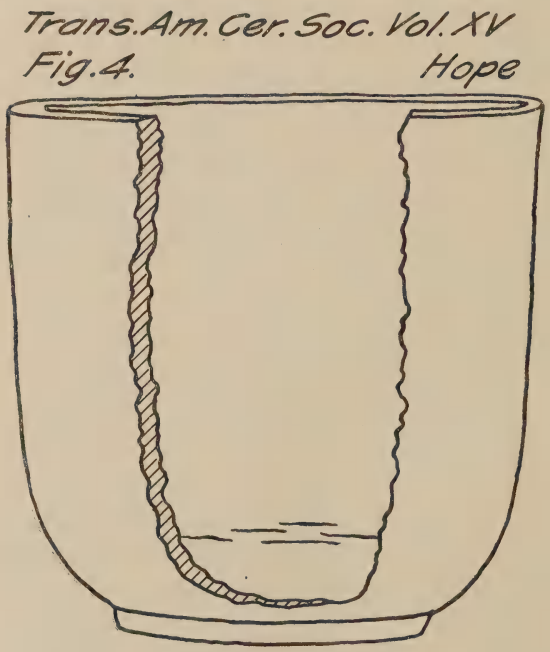
certain rapidity of drying is absolutely necessary, and under the proper conditions, may, no doubt, be had with perfect safety. Just exactly what those proper conditions are, the writer does not presume to say, but generally speaking they should be those which permit the ware to dry equally all over and all through. If it could be arranged suitably for small ware, a drying system in which the degrees of heat and humidity are under perfect control should give excellent results.

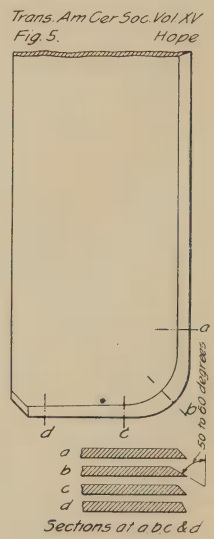
Jigger Tool. The question of the thickness of the jigger tool was given attention only after all the above factors had been well considered and experimented with, but it proved a matter of the greatest importance, and a change in the thickness of the tools effected a much greater reduction in loss than anything else that had been tried. The usual thickness of jigger tools with us is $\frac{3}{16}$ inch, some being $\frac{1}{4}$ inch thick, the cup and bowl tools being for the most part without any wood backing. By the use of tool $\frac{3}{32}$ inch thick, the loss was reduced very considerably, this being true not only in the case of cups and mugs, but also of straight sided individual creams which had previously given very serious trouble from the vertical cracks already referred to. Tools even thinner than the above were tried, but as light as $\frac{1}{16}$ inches they spring so easily that it is extremely difficult to keep them in the center of the piece. It should be mentioned also that it takes slightly longer to make the ware with a very thin tool on account of the fact that the clay does not so readily fill in and level up the inequalities of the partly made piece.

It would appear that the effect of the thicker tool is to make the ware very dense and compact on the surface; and when the interior, being more open and naturally having greater shrinkage, begins to contract, the outer and denser portion cannot contract with it and must, therefore, give way. The thinner tool cuts the clay faster and would not have the same tendency to produce great density on the surface, hence a more equal contraction results. This theory may or may not be correct, but at least it appears reasonable.

Figure 4. Cracks of another kind, but occurring in the same class of ware as the foregoing, are those running horizontally, inside as before, and at the lower part of the side where the latter

merges into the bottom (see Fig. 4). These are usually visible when the ware is removed from the moulds, and at that time may often be permanently closed by pressure with the end of the finger. Even so, however, the time taken to close the cracks in this way is considerable, and the results often uncertain, so that measures must be taken to stop them altogether. This is usually accomplished by bevelling the tool to a very sharp angle, say 50 degrees to 60 degrees from the perpendicular, just at the turn of the tool where the cracks occur, as indicated in Figure 5. The usual angle of our tools is about 25 degrees from the perpendicular.



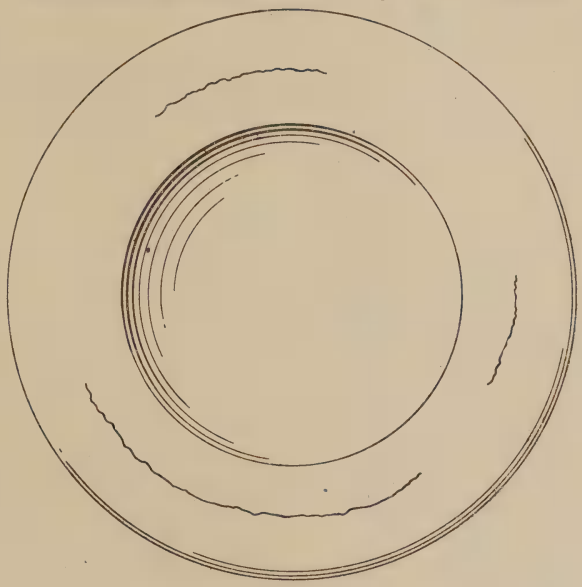


SURFACE CRACKS ON PLATE RIMS

As indicated in Figure 6, this crack occurs about the middle of the rim of the plate, varying in length from half an inch to almost the entire circumference of the plate, and in depth from $\frac{1}{64}$ inch to nearly or quite through the thickness of the plate.

The writer has not been able to ascertain the exact course of these cracks; but as far as his observation goes, they are almost always found in ware having a more or less deep center, a rim soup plate being the most common and typical example. This particular crack is always worse if the piece is perfectly plain, no embossed work, and is worse in thin than in thick ware. We have found a partial remedy to lie in soft moulds; though if moulds of ordinary hardness are kept damp, the loss from cracks

Trans. Am. Cer. Soc. Vol. XV Fig. 6. Hope



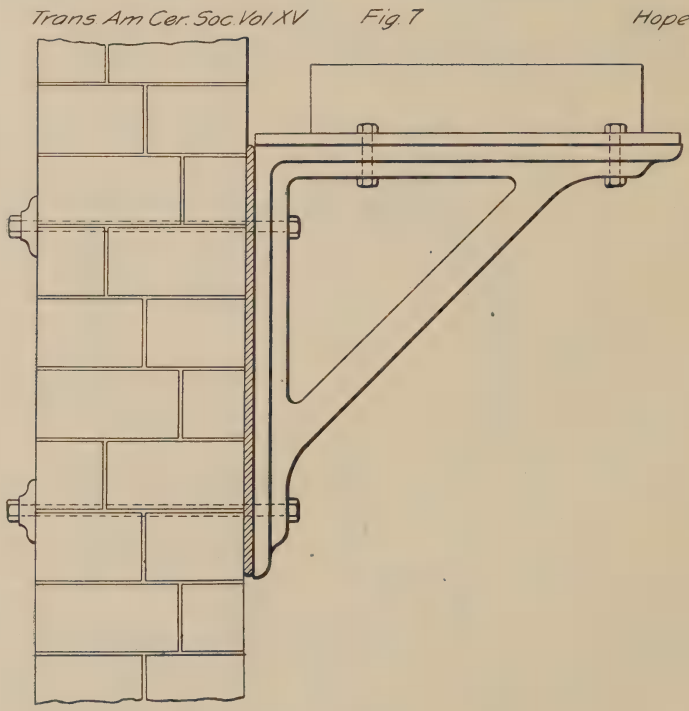
of this character will be reduced. If the moulds are oiled before using and from time to time when in use, this crack can be overcome to a large extent in every case.

SUPPORTS FOR BATTING-OUT BLOCKS

The most common form of support for batting-out blocks is a small, solidly built, square table, topped with flat stone, upon which is cast the plaster block, either round or square as suits the

requirements of the presser, dishmaker, or jiggerman's batter-out as the case may be.

There are two serious objections to this form of support, the first being that it is generally impossible to prevent the adjacent bench being jarred when a bat is being made; and the second that the feet of the batter-out will come in contact with the legs of the support, preventing his standing close to the block, which



would make his work easier. So far as general stability and freedom from vibration are concerned, a decided improvement is to make the support of solid concrete, the latter resting on an equally solid foundation, preferably the ground. A support which entirely eliminates both the objections previously referred to, is in the form of a pair of large iron brackets which can be bolted to a brick wall or something equally substantial. These brackets, which

are shown in Figure 7, are of the dimensions given, namely each arm 28 inches long by $3\frac{1}{2}$ inches wide, and each is bolted to the wall by two $\frac{5}{8}$-inch or $\frac{3}{4}$-inch bolts, about 12 or 13 inches apart. The top upon which the plaster block rests may be an iron plate bolted to the horizontal arms of the bracket or else the usual flat stone. In order to entirely eliminate all vibration, it is necessary to place several thickness of rubber packing between the brackets and the wall before the bolts are drawn tight. With an arrangement of this kind, even the heaviest blow from the batter upon the block will not jar the bench in the slightest degree, provided, of course, that the latter does not actually touch the batting-out support. In addition it is found that much of the strain on the wrists of the batter-out is removed, a fact that is appreciated by dishmakers and others who have to make bats of a large size.

DISCUSSION

Mr. Ward: I would like to ask Mr. Hope if he experienced any trouble in getting the clay removed from his chum?

Mr. Hope: No, we don't make much ware in that way; but when we do, we use a wooden chum with plenty of oil on it, and that releases the clay very readily. Of course you can put it on with a cloth and then pull the cloth out.

Mr. Ward: When you use oil, don't you experience trouble in your ware? Don't it cause cracking?

Mr. Hope: Oh no, the oil would be taken out by the tool, anyhow; it would come out in the scrap, but even if it did not, I don't think there would be any trouble. I have not been able to attribute any trouble to that source.

Mr. Simcoe: I would like to ask Mr. Hope to bring out the point why he wanted to eliminate the vibration from the block at the jigger bench?

Mr. Hope: Well, perhaps it is not quite as important at the jigger bench as at the pressers' benches. It is important at the jigger bench, too, because there would be a great deal of the dry ware, and vibration would strain a great deal of it; there would be considerable loss, I should say.

Mr. Simcoe: What about the man using the pull down himself?

Mr. Hope: I should not think it would affect the jigger itself. It should be so firmly bolted down that vibration would not affect it in great measure; but it might affect it in some slight way, and it would be well to have as little vibration as possible on that account, also.

Mr. Purington: Isn't the jar often due to the box being over a beam? Isn't the jar often transmitted to the stilliards and ware broken in that way?

Mr. Purdy: This vibration idea is very important. Our company experienced considerable cracked ware in a certain dryer. The ware in that dryer was just the same as it was in all the other dryers, and they could find no reason for it until they noticed that the floor had a slight quiver due to the machine below. When we stopped that machine, we stopped our cracking.

THE CLARK VISCOSIMETER[1]

BY WARREN E. EMLEY, CH.E.

In the *Transactions* for 1910 was described an instrument for measuring the viscosity of clay slips, which was designed by Mr. H. H. Clark. The instrument used for that work was the first one of the kind constructed, and, as was to be expected, actual use brought to light several mechanical imperfections. To correct these as well as the more important defect that the original instrument was not strong enough to be used with very thick slips, a new viscosimeter has been built, which operates on the same principle, but is of different mechanical construction. This new instrument is shown by the photograph Figure 1, and the detailed design, Figure 2.

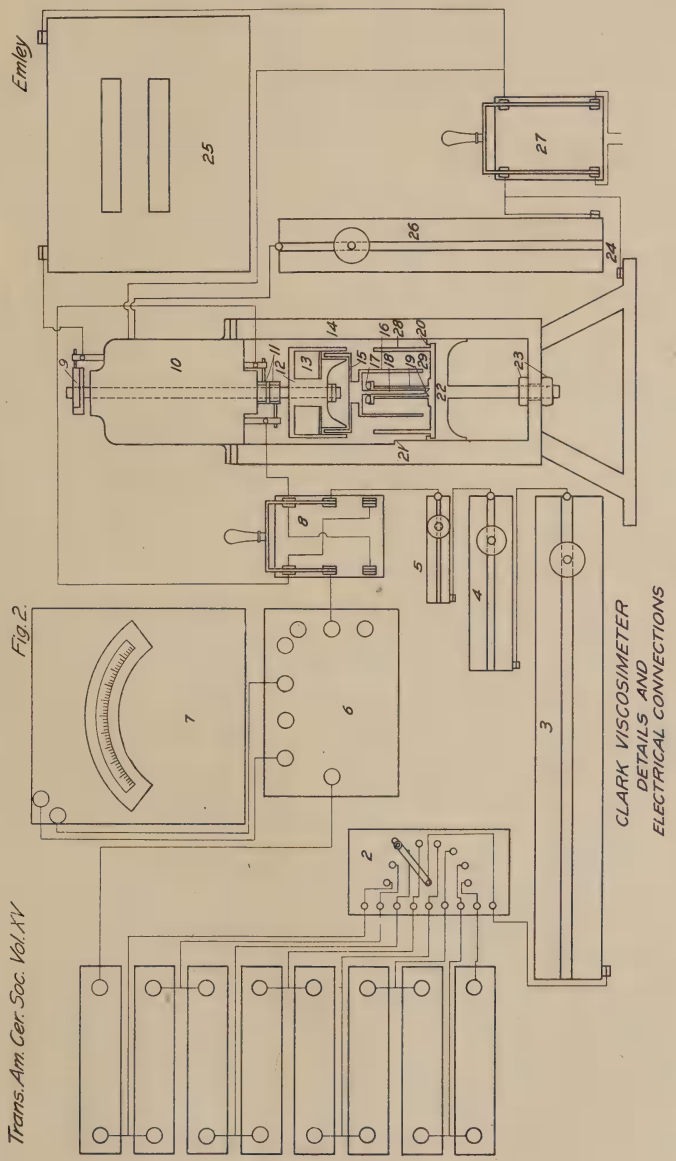
As stated in the article referred to above, the apparatus is designed to measure the torque required to turn a paddle immersed in the liquid whose viscosity is to be measured. The method of construction is as follows:

CONSTRUCTION OF IMPLEMENT

The square tub, 28, is designed to hold the liquid, and is mounted on the movable head, 22, being held in place by the lugs, 20. The head is prevented from turning by the guide, 21, and is held at the required height by the lock nuts, 23. Inside of the tub is mounted the hollow cylindrical paddle, 16, carried by the shaft, 18. This rests upon the jewel, 19, and the side thrust is taken up by the steel knife edge, 17, so that the paddle is free to rotate with very little friction. To the upper part of the paddle is attached the brass cylinder, 15, to which the torque is applied. An electromagnet is rotated in such a manner that the cylinder is included between its poles. Rotation of the magnet therefore causes the cylinder to cut the magnetic field, which generates an electro-motive force in the cylinder. The resultant of these two forces is a torque tending to turn the cylinder (and therefore the paddle) in the

[1] By permission of the Director of the National Bureau of Standards.

Fig. 1


Emley
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CLARK VISCOSIMETER
DETAILS AND
ELECTRICAL CONNECTIONS

Fig. 2.

direction of this magnet. By this means, the paddle is rotated without mechanical connection, and friction from this source is eliminated. The outer pole face of the magnet is shown at 12; the inner at 14. The magnet is mounted on the lower end of the shaft of the motor 10, by means of which it is rotated.

It is evident that the torque applied will depend upon three factors: 1. The area of the cylinder exposed to the magnetic action. 2. The relative speeds of the magnet and cylinder. 3. The intensity of the magnetic field.

The first factor is controlled by the position of the lock nuts, 23. In all experiments which have been carried out, these nuts have been kept in the same position, so that for present purposes, this factor may be considered constant.

The strength of the field of an electro-magnet, being dependent upon the strength of the exciting current can be accurately controlled and measured. It was therefore determined to make this factor the variable. Consequently some means had to be devised for maintaining a constant ratio between the speed of the magnet and the speed of the paddle.

The $\frac{1}{30}$ H.P. motor, 10, is connected to a 220 volt D. C. circuit through the main line switch, 27. In series with it is a 2500 ohm slide wire rheostat, 26, by means of which the speed is maintained constant at 1600 r.p.m. The speed is indicated by means of the make-and-break piece, 9, and the frequency meter, 25. This make-and-break piece is a pulley whose circumference is divided into 6 parts, which are alternately brass and fibre. The current, which passes from the main line switch, 27, through the brush to the make-and-break piece, through the frame of the instrument, and out at the binding post, 24, is made and broken six times per revolution of the motor. These "alternations" are indicated by the frequency meter, 25, in series with the above circuit.

The speed of the paddle is indicated by an optical device, as follows: The outer circumference of the cylinder, 15, is divided into 100 strips parallel to the axis, which are painted alternately black or white. In the outer pole face of the magnet, 12, is cut a slot having the dimensions of one of these strips. If the magnet rotates 50 times as fast as the paddle, then, whenever the slot passes the eye of the observer, it will reveal a white strip on the

cylinder, with the result that the white strips appear to stand still. If the cylinder is going to fast or too slowly the strips will appear to move in the same direction as the magnet, or in the opposite direction. The speed of the paddle is regulated by varying the current which excites the magnet. If the speed of the magnet is adjusted to 1600 r.p.m., by means of the rheostat, 26, and the speed of the paddle is such that the white strips appear to stand still (the speed of the paddle will then be $\frac{1}{50}$ of 1600 or 32 r.p.m., then the torque applied will depend upon only one variable —the strength of the magnetic field.

The current used to excite the magnet is taken from the 8-cell storage battery, 1, by means of the eight-way switch, 2, any number of cells may be used. This arrangement, together with the slide wire rheostats, 3 (220 ohms), 4 (8 ohms), and 5 ($\frac{1}{2}$ ohm), gives very accurate regulation of the current. The two way switch, 8, permits reversal of the current through the magnet, so that any errors due to residual magnetism or hysteresis may be eliminated. The current is introduced through the collector rings, 11, into the magnet coils, 13. It is measured by means of the shunt 6 and the millivoltmeter 7. These are so designed that by use of different binding posts on the shunt, the full scale reading of the millivoltmeter will indicate, $\frac{3}{10}$, $\frac{1}{2}$, or $7\frac{1}{2}$ amperes.

VISCOSITY

The coefficient of viscosity of a substance is closely analagous to the coefficient of internal friction. Viscosity is stated in one of two ways: either as absolute viscosity, which may be defined as the force required to move 1 sq. cm. of the material over another square centimeter in one second, and is expressed in units of dynes per square centimeter; or as specific viscosity, which is the ratio between the viscosity of the substance and that of some standard. When results are stated as specific viscosity, a full knowledge of the apparatus and of all experimental conditions is necessary for their correct interpretation. The absolute viscosity is therefore to be preferred whenever the measurements are carried out in a way which will permit of its use.

CALIBRATION

Unfortunately, the mechanical design of this instrument offers serious mathematical difficulties when attempting to transform the results obtained with it into units of absolute viscosity. This is chiefly due to the square tub, with the resultant eddy currents in the corners. However, it is believed that the following method of calibration gives results which are sufficiently accurate for the present purpose.

The instrument was set up with the tub empty. To the circumference of the cylinder 15 was fastened a thread, the other end of which was attached to the pointer of a balance. The magnet was rotated at 1568 r.p.m. (1600-32, because the cylinder was not permitted to move, and the rate of cutting the lines of force must be maintained constant). The strength of the exciting current was varied, and the torque developed was measured by placing weights on the balance pan. The results are shown by the curve, Figure 3.

To find an approximate relation between the exciting current and the viscosity, the following calculation was used: Let w equal the weight in grams on the balance pan, which counterbalances the torque developed by a given current. The force exerted by gravity on this weight will be 981 w dynes. This force times its lever arm (the length of the arm of the balance is 11.35 cms.) is equal to the moment about the knife edge of the balance, equals 11134.35 w. The moment exerted by the exciting current is equal to T (the torque) divided by 3.80 (the outer radius of the cylinder) multiplied by 9.56 (the distance from the knife edge to the thread, measured along the pointer) equals 2.52 T. Since the system is in equilibrium, these two moments must be equal, or 11134.35 w equals 2.52 T; whence T equals 4425.79 w, T being the total torque exerted to turn the paddle by the given exciting current.

If we consider the case of a flowing stream, we find that a plane near the surface will move faster than a parallel plane nearer the bottom. The difference in velocity between the planes divided by the perpendicular distance between them, may be called the velocity gradient through the liquid. Then, by definition, the

Trans. Am. Cer. Soc. Vol. XV Fig. 3. Emley
Calibration Curve
Actual Measurements
Weight on balance pan - Grams
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2 1.3 1.4
Current in magnet measured in amperes

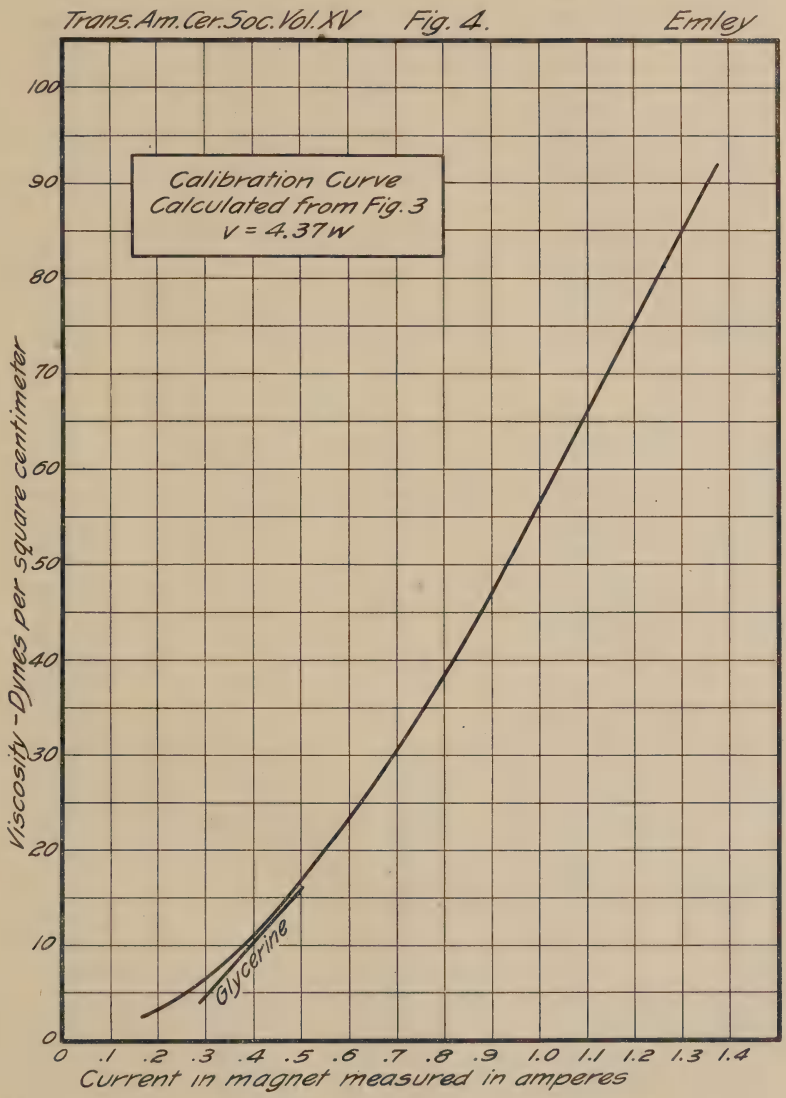
viscous resistance of the liquid is equal to the velocity gradient multiplied by the coefficient of viscosity.

In order to apply this principle to the problem at hand it becomes necessary to make several assumptions, which are not strictly vigorous or at least not capable of present proof, but which are thought sufficiently accurate to permit of their use: First, assume that wherever the liquid is in contact with the tub, it is at rest, and that there is a uniform gradation of velocity (no eddy currents) between the stationary box and the moving paddle. Second, assume that the torque exerted will be uniformly distributed over planes of the liquid parallel to the surface of the paddle.

From the first assumption it is evidently possible to consider the tub as being replaced by a cylinder of such a radius that the velocity gradient between the paddle and cylinder is equal to the mean velocity gradient between the paddle and tub. If x equals half the least diameter of the tub, then the radius of such a cylinder would be r equals $\int_{a=o}^{a=\frac{\pi}{4}} \times \textit{seca da}$, divided by $\frac{\pi}{4}$, equals 1.12 x. Since x equals 3.97 cms., r equals 4.45 cms.

From the second assumption, the total torque may be considered as divided into three parts proportional to the areas of the outside, inside and bottom surfaces of the paddle respectively. Call these three parts a, b, and c. The torque a, divided by its lever arm 2.22 (the outside radius of the paddle) gives the total force exerted on the outer surface. This force, divided by the area of surface, $2 \times \pi \times 2.22 \times 4.10$ (4.10 cms. being the depth the paddle is immersed in the liquid) gives the intensity of the force, and is equal to $\frac{a}{126.90}$ dynes per square centimeter. Similarly, the intensity of the force on the inner surface is $\frac{b}{113.55}$; and on the bottom, $\frac{c}{3.52}$ per square centimeter.

If the paddle rotates 32 revolutions per minute, then the linear velocity of a particle on its outer surface is $\frac{32 \times 2 \times \pi \times 2.22}{60}$ equals 7.44 cms. per second. By the first assumption, the velocity of

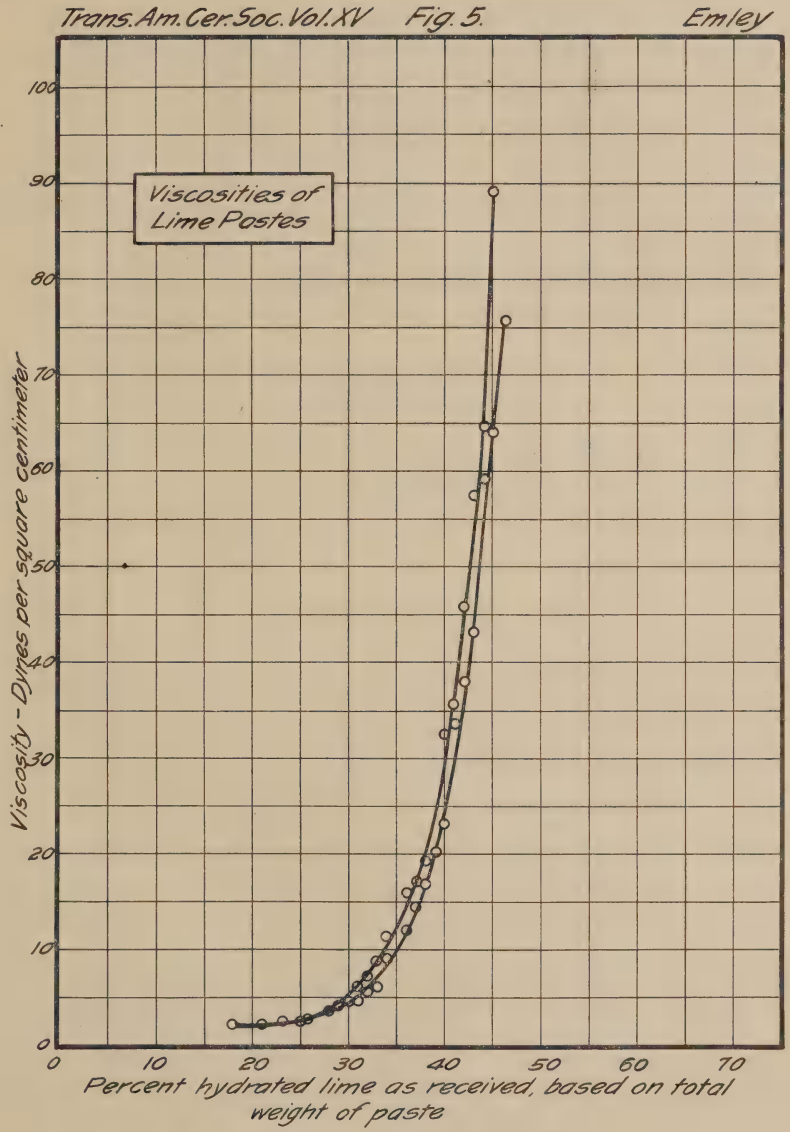

Trans. Am. Cer. Soc. Vol. XV
Fig. 4.
Emley
Calibration Curve
Calculated from Fig. 3
V = 4.37 W
Glycerine
Viscosity - Dynes per square centimeter
Current in magnet measured in amperes
0
10
20
30
40
50
60
70
80
90
100
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2 1.3 1.4

a particle in contact with the tub is zero. The velocity gradient through that part of the liquid between the outer surface of the paddle and hypothetical cylinder replacing the tub, is $\frac{7.44}{4.45 - 2.22}$ equals 3.34. Similarly, the velocity gradient between the inner surface of the paddle and the sleeve protecting the bearings is 4.57; that between the bottom of the paddle and the bottom of the tub is 20.10.

Since the system is in equilibrium, that is, the speed of the paddle is neither increasing nor decreasing the force exerted must be equal to the viscous resistance of the liquid (plus the mechanical friction, which is neglected). If n is the coefficient of viscosity, then by definition, $\frac{a}{126.90}$ equals $3.34\,n$, $\frac{b}{113.55}$ equals $4.57\,n$, $\frac{c}{3.52}$ equals $20.10n$. But a plus b plus c equals the total torque exerted to turn the paddle, equals 4425.79 w. Solution of these four equations gives the relation n equals 4.37 w. The weights used in the experimental curve 3, were therefore multiplied by the constant, 4.37, and the results plotted as dynes per square centimeter, in curve 4. By means of this curve the readings obtained from the instrument can be transformed directly into dynes per square centimeter—the absolute units of viscosity.

It was desired to check this curve by actual experiment, but a study of the literature seems to show that very viscous liquids either have not been investigated or the results have not been reported in absolute units. The liquid finally selected was glycerine, which has a high viscosity at low temperatures. The figures given in the Smithsonian Physical Tables have been plotted against the observed readings of the instrument in the lower curve, Figure 4. The two curves seem to agree closely when it is considered that the instrument is not provided with a constant temperature bath, and that the readings with glycerine appoach the lower limits of accuracy of the instrument This would seem to indicate that the assumptions made are sufficiently near the truth to answer the purpose for which the instrument was designed

The instrument does not appear to be accurate below 0.25 amperes, probably because the difficulties of controlling and meas-


Trans. Am. Cer. Soc. Vol. XV Fig. 5. Emley
Viscosities of Lime Pastes
Viscosity - Dynes per square centimeter
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70
Percent hydrated lime as received, based on total weight of paste

uring the current become pronounced, and the friction can no longer be neglected. This limit could be extended by changing the position of the lock nuts, 23, so that less area of the cylinder 15 is exposed to the magnetic field, and consequently more current would be required to produce the same torque. This would require recalibration of the instrument, which might be advisable, because the viscosity of water is about 0.01 dynes per square centimeter, which cannot be measured with the nuts in their present position. Owing to a slight inaccuracy in the shunt, it becomes necessary to correct any reading greater than 1.5 amperes. However, this limit is sufficiently high to include lime pastes thick enough for practical use.

EXPERIMENTS

The results of measurements of the viscosities of lime pastes are shown by the curves in Figure 5.

MAT GLAZES

BY FORREST K. PENCE, OHIO STATE UNIVERSITY

INTRODUCTION

It is the purpose of this paper to give further evidence in support of the theory advanced by the author in the paper on "Theory of Cause of Matteness in Glazes," Vol. XIV, *T. A. C. S.* This evidence constitutes chiefly the result of a study of the stages of development through which a mat glaze passes in the process of its firing treatment.

Microscopic examinations were made by Dr W. J. McCaughey, of the Ohio State University, whose services are hereby gratefully acknowledged. The data given in describing the observations made with the microscope are recorded from the dictation of Dr. McCaughey; but the author is solely responsible for all deductions and conclusions drawn from these and other observations described in this paper.

THE CALCIUM-ALUMINA TYPE

A microscopic examination was made of the mat glaze which was developed from frit Z described in Vol. XIV, p. 683. The surface has an equi-granular appearance, i.e., like microscopic grains of sugar The glaze itself is permeated with an aggregate growth of very tiny needle-shaped crystals The intergrowth is so great that it would appear to produce the granular texture. The crystals are so small as to be visible only under a lens giving a magnification of approximately 400 diameters. Because of their small size, it is difficult to describe the crystal form or estimate the percentage of the mass which is constituted by the crystalline matter They are, however, scattered homogeneously throughout the glassy matrix

A raw glaze of the same formula as frit Z, viz:

$$\left.\begin{matrix} 0.50 & PbO \\ 0.15 & K_2O \\ 0.35 & CaO \end{matrix}\right\} \; 0.35 \; Al_2O_3 \; \{ \; 1.6 \; SiO_2$$

was applied rather heavily on a 3 inch by 3 inch bisque tile and

fired to cone 02. The firing, or rather the cooling treatment, was somewhat abnormal as is shown by the result, viz., the tiles show a mat border starting from the edges where the glaze is thinnest and extending inward about $\frac{1}{4}$ inch. The interior of the tile is a transparent glass, similar to a bright glaze, with very small dull spots distributed over it. These spots have the appearance of crystal growths, as noted by slight branches protruding from them. A tile of this description was re-fired to cone 02 under normal firing treatment, and came from the kiln with its entire glazed surface possessing the mat texture.

In the first case, the crystal growth started at the edge where the influence of the foreign matter represented by the body was relatively greatest. This is in accordance with crystalline glaze phenomena. In the second fire, opportunity was given for crystallization to complete itself, and we have the fully developed mat texture.

That this matness represents the development of a crystalline structure is confirmed by the microscopic study of the glaze. The mat portions are permeated with very tiny needlelike crystals as in the case of the glaze from frit Z.

Glaze A. Tiles, upon which had been applied a raw glaze of the above formula, were placed in a commercial kiln, and provision was made for drawing them when desired.

One tile (A1) was drawn five hours before the kiln was finished, one tile (A2) when the finishing condition at cone 02 was reached, and one (A3) was left in the kiln to cool at normal rate. The total time of firing was about thirty-six hours.

A1 shows a glossy or bright, smooth surface. The glaze is permeated with small bubbles. Undissolved matter is low in amount.

A2 similar to A1. Very little undissolved matter, practically none as regards its possible effect upon matness. Bubbles are less in evidence. Surface is smooth and bright.

A3. This tile shows the characteristic mat texture of the calcium-alumina type mat. A microscopic examination of the surface shows it to be equi-granular as in case of glaze from frit Z. The texture here appears, however, to be finer than in the former glaze. The glaze is permeated with very tiny rod-like crystals

of about $\frac{1}{1000}$ mm. by $\frac{6}{1000}$ mm. in size. It is difficult to estimate the percentage but it is relatively high.

The crystals appear to be of the same type as in glaze from frit Z, but are not so densely intergrown as in the case of the fritted glaze. There is considerable undissolved matter present, but the proportion of crystals predominates over that of the undissolved matter.

It is difficult to estimate the proportions in terms of percentage of the mass because of the very fine condition of the undissolved matter and the very small size of the crystals.

Glaze B. A glaze of formula:

$$\left.\begin{matrix} 0.55 & PbO \\ 0.15 & K_2O \\ 0.30 & CaO \end{matrix}\right\} 0.35\ Al_2O_3 \left\{ 1.6\ SiO_2 \right.$$

was applied to tiles which were drawn from the kiln as in A, one being left to cool with the kiln. The glaze shows the same phenomena as in A, and the microscopic examination shows the same character of surface and crystal growth.

Glaze C. This glaze has formula:

$$\left.\begin{matrix} 0.55 & PbO \\ 0.15 & K_2O \\ 0.30 & CaO \end{matrix}\right\} 0.4\ Al_2O_3 \left\{ 1.6\ SiO_2 \right.$$

This glaze with the same treatment and examination as in case of A and B shows the same results, except that in this glaze the proportion of undissolved matter is relatively higher than in A or B, which would be explained by the presence of higher alumina.

The glaze from frit Z and the other glazes thus far described all show the same texture of surface and the predominating influence of tiny crystals distributed uniformly throughout the glassy matrix. The evidence, therefore, points decidedly to crystallization as a direct or indirect cause of matness in the calcium-alumina type of mat glaze. I may state in this connection that a number of other glazes of this type were examined and all showed this same crystalline development and phenomena. Thus we are led to the same conclusions as were drawn from the observation of the working properties of such glazes and which were set forth in the original statement of theory in Vol. XIV.

THE ZINC CRYSTAL TYPE

This glaze is not of the type described in the various articles on crystalline glazes which appear in the *Transactions of the American Ceramic Society*. We have an example of the zinc crystal mat in the formula of the following raw glaze.

Glaze D.

$$\left.\begin{matrix}0.15 & K_2O \\ 0.35 & ZnO \\ 0.50 & PbO\end{matrix}\right\} \; 0.25 \; Al_2O_3 \; \{ \; 1.75 \; SiO_2$$

This glaze would be bright in the ordinary firing treatment of a small kiln. My statement concerning the difficulty of obtaining certain results in the laboratory kiln will be confirmed by any who have had commercial experience with mats of the above type. In the light of the literature on crystal glazes one would not expect a glaze of such high Al_2O_3 and medium ZnO content to crystallize.

The treatment here is the same as in the preceding examples.

D1 was drawn from the kiln five hours before the finishing heat. This shows a transparent glass beneath which the body is plainly visible. There are some patches of undissolved matter evident, also some rather large bubbles in some portions of the glaze.

D2 is similar to D1, except that undissolved patches and bubbles have practically disappeared.

D3, cooled with the kiln, gave a mat texture. The texture is much coarser than that of the calcium-alumina glazes and feels slightly coarse or rough to the touch. The glaze is shown to be permeated with an interlacing growth of relatively large, rod-like, crystals uniformly distributed throughout the glass. The texture of the glaze is undoubtedly determined by the development of these crystals and is characteristic of the development of mat texture in glazes of the zinc crystal type. Other glazes of this type were examined and confirm the observations on glaze D.

THE BARIUM MAT

The barium mat has been considered as belonging to the type known as mats of immaturity. This is particularly indicated by Professor Orton's study of such glazes in Volume X, *T. A. C. S.*

Glaze E.

$$\left.\begin{matrix} 0.15 & K_2O \\ 0.05 & ZnO \\ 0.15 & PbO \\ 0.30 & CaO \\ 0.35 & BaO \end{matrix}\right\} \quad 0.25 \quad Al_2O_3 \quad \{ \quad 1.88 \quad SiO_2$$

E1 and E2 appear very similar, so minute examination was given to E2, which was drawn at the finishing heat of the kiln. The surface appears bright and glassy. Under the microscope, it shows irregularities relatively large. The fracture is glassy. The mass is transparent to a very considerable degree, as evidenced by the illumination of the small bubbles present in lower portions of the glaze. The glaze is permeated with bubbles and the surface is more or less broken by them. There is considerable undissolved matter present, but a striking feature is a rather prominent glassy layer at the surface that is practically free from undissolved matter.

E3 was cooled normally and shows a smooth mat surface. Under the microscope the surface is seen to be characterized by irregularities that are described as being very fine and which give a very even texture. The glaze has become stoney in fracture and comparatively opaque, as the bubbles below the surface do not show illumination. The bubbles are much less in evidence than in E2 and are unimportant. There are two types of crystals present. A small bladed or plate-like crystal which is, however, very subordinate in proportion to the other type. The mass is permeated by very small needle-like crystals. The proportion of crystalline matter present is estimated at from 15 percent to 25 percent of the mass. Undissolved matter is present but is less in proportion than the crystals. The non-glassy portion is predominantly crystalline.

Another glaze of this type was given similar treatment and examination.

Glaze F.

$$\left.\begin{matrix} 0.10 & PbO \\ 0.15 & K_2O \\ 0.10 & ZnO \\ 0.35 & CaO \\ 0.30 & BaO \end{matrix}\right\} \; 0.233 \; Al_2O_3 \; \{ \; 1.90 \; SiO_2$$

F1 and F2 appear the same as E1 and E2.

The same prominence of bubbles and the glassy layer at the surface is in evidence here as in the case of Glaze E.

F3 shows the very finely irregular surface described in the case of E3. The glaze is permeated by the blade-like crystals and the fine needle crystals, but in this glaze the blade-like crystals predominate. The crystals appear somewhat larger and more profuse than in E3. The distribution throughout the mass is very uniform.

It is seen, therefore, that in glazes of this type, the observations indicate that crystallization is the basis of mat development. Thus the theory of crystallization as a cause of matness is shown to have an even wider application than was at first anticipated.

CONCLUSION

The evidence is certainly very strong that in glazes of the three general types which are typical in composition and normal in treatment, a causal relation exists between crystallization and the development of mat texture. That this crystallization occurs after the manner set forth in my first paper is shown by the comparison of the glaze drawn from the kiln at finishing condition and cooled rapidly with the one remaining in the kiln and cooled slowly. In the case of both the calcium-alumina mat and the barium mat the crystals are very tiny, and although the proportion of crystalline matter in the mass may not be more than 20 percent, the amount of crystalline surface area effective in causing light diffusion is relatively large because of the smallness of the crystal.

It is noted that the surface of these glazes containing the very small crystals are characterized by very fine or small and even irregularities, while in case of the coarse crystallization of the zinc

mat the texture is correspondingly coarse. In all cases the crystals are distributed uniformily, asserting their influence at the surface as well as throughout the mass. A number of other glazes belonging to these types were given cursory examination and confirmed the findings of this paper. These results are not surprising, since we know that the strong tendency in similar magmas is for crystallization to take place.

I may say, however, that in the case of glazes containing considerable coloring agent in the form of undissolved stain, etc., these may obscure the small crystals and make their observation much more difficult.

The author recognizes that certain specialized types of mat may be produced by entirely different phenomena, as by vesicular structure, etc. Also that mat surfaces are obtained by the use of coatings that never reach a glassy state and are plainly in a stage of immaturity. These latter will not in firing heal defects present in the unfired coating, and the texture will not have the smoothness of the true mat. Sometimes this roughness in texture is desired for certain artistic applications. I do not think, however, that such coatings should be classified with glazes proper.

The evidence of this paper indicates very strongly that in true mat glazes, i.e., those that flow and heal readily giving a smooth, even coating of smooth texture, the glaze behaves in every way analogous to a bright glaze, except that not all of the components may enter into solution and that on cooling segregation of crystals from the glassy matrix takes place.

In conclusion we would say that the practical application of this theory serves to guide the ceramic chemist in the right direction in the researches of mat glaze development. Mat glazes group themselves into types. For a given heat treatment, the limits in composition *giving best results* are not only rather narrow but are characteristic of the type of glaze used. The proper conception is not the overloading of the glaze with clay or whiting or barium carbonate in accordance with the idea of preventing solution. The best results are obtained in a given type of glaze when the proper proportions are present to facilitate most effectively the process of solution and subsequent crystallization.

PROPERTIES OF PORTLAND CEMENT AS AFFECTED BY DIFFERENT BURNING TEMPERATURES

BY P. H. BATES, BUREAU OF STANDARDS, PITTSBURGH, PA.

Purpose of the Investigation. In some previous investigations[1] of the constitution of Portland cement, which were made at the Pittsburgh branch of the Bureau of Standards, it was noticed that when the percentage of lime present in the raw mix was increased, the amount of tricalcium silicate and tricalcium aluminate also increased, accompanied by a decrease in the amount of orthosilicate of lime and the disappearance of the $5CaO.3Al_2O_3$ compound. As however to satisfactorily burn the higher limed material, a higher temperature was needed, it was thought a series of experiments would be of interest in which a group of raw mixes of different lime, or silica, or alumina, content would be burned at different temperatures. The resulting clinker would then be examined for changes in constitution; and also after grinding and plastering, the time of set, soundness and specific gravity and ordinary small physical specimens would be made, thus attempting to secure some relation between the constitution, the composition, the burning temperature and the physical properties of the burned cement.

Method of Conducting Investigation. It was not attempted to make the burnings in the experimental rotary kiln of this bureau, since it was not deemed necessary to make burnings of large amount of material. By making use of a furnace in possession of Clay Products Section of the bureau[2] it was possible to make all the burnings at any one temperature at one time, until it was desired to exceed 1400°, when a specially constructed furnace was used, of the same general character but smaller in size. In these furnaces the flame did not directly strike the material but the later was protected by some magnesite brick. This was of course

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[1] "The Constitution of Portland Cement." Paper read before the Ninth Annual Meeting, National Association of Cement Users, December 1912, by P. H. Bates. Published in *Concrete and Cement Age*, January, 1913.

[2] *Transactions of American Ceramic Society*, Vol. XII, p. 341.

not simulating rotary kiln practice, where the flame strikes the raw material, but it was necessary in order that the material should reach and maintain a uniform temperature.

The temperatures at which the material was burned were 1100°, 1200°, 1300°, 1350°, 1400°, 1450° and 1500°. The temperature was determined by a thermocouple. The raw material was mixed with water to the consistency of a stiff mud and molded into bars about 1 in. by 1 in. by 4 in. After drying these were built up in the furnace in a "checker board" fashion, exposing a great amount of surface to the hot gases. The rate of heating was such that 1450° was reached in two and one-half hours, this temperature was held one-half hour longer when the gas was shut off and air blown into the furnace. The burns at lower temperatures were made in a slightly shorter time; that at 1500° required an hour longer.

At each temperature three different raw mixes were burned, the raw material having been proportioned so as to give approximately in each case:

	"A"	"B"	"C"
SiO_2	22.9	19.8	23.1
Al_2O_3	7.6	7.6	6.0
Fe_2O_3	2.7	2.7	1.5
CaO	65.2	68.3	68.2
MgO	1.6	1.6	1.2
	100.0	100.0	100.0

The relation between these mixes is evident. Thus in A and B there is the same iron oxide-alumina content, while the silica varies at the expense of the lime; in A and C there is about the same silica content, while the iron oxide-alumina content is varied at the expense of the lime and in B and C there is the same lime content, while the silica is varied at the expense of the iron oxide-alumina content.

In making these mixes the raw material for A was limestone and clay, to which a small amount of ground flint was added, as its alumina content was a littler higher than desired. Also some iron oxide was added in order to secure a relation between it an

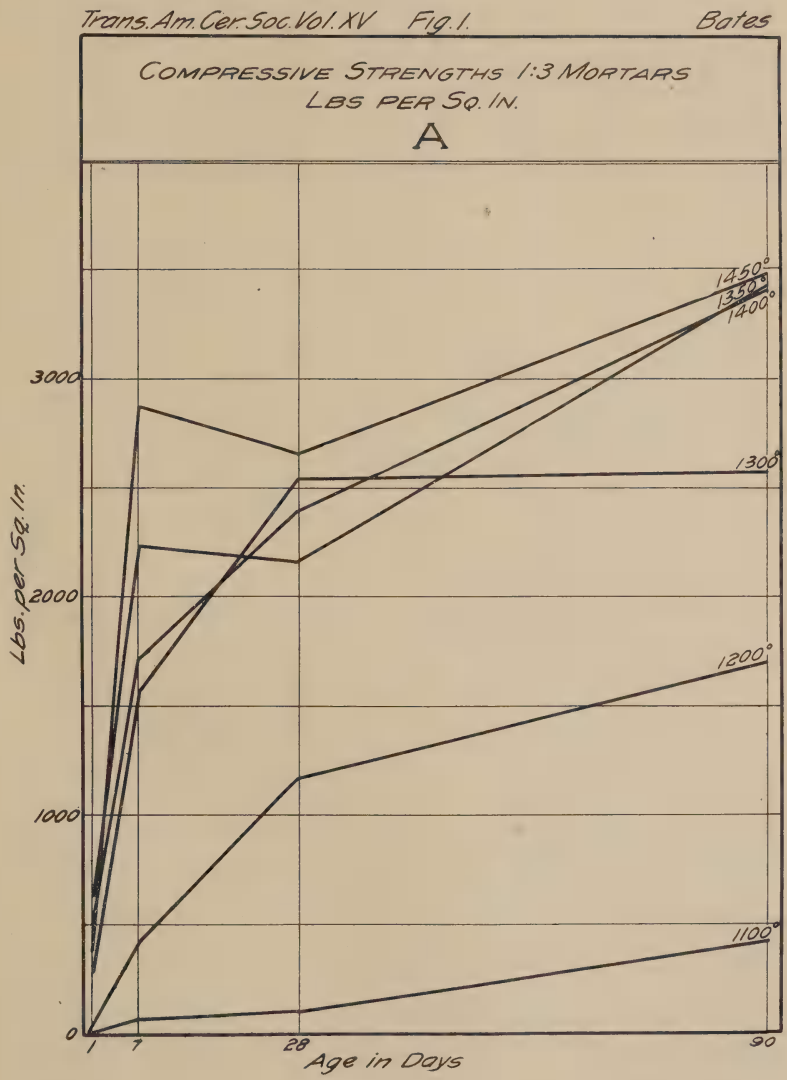
the alumina content approaching a little more closely commercial mixes. In mix B the lower silica and higher iron oxide-alumina content was secured by replacing some of the clay with North Carolina kaolin and iron oxide. In mix C the lower iron oxide-alumina and higher lime content was attained by replacing some of the clay with soda spar and increasing the limestone content.

Some objection may be raised against the use of different raw materials in making different clinkers which are to be compared with one another. However, at present the evidence seems to point rather strongly to the fact that at least the same resulting physical properties from the ground clinker can be secured whatever the raw material used. The cement rock-limestone mix of the Lehigh district, the marl-clay mix of the Northern Central district, the limestone-clay mix of the Middle West district, and the slag-limestone mix of the Steel Corporation plants, all give cements approaching very closely to one another in physical properties. It is evident therefore that if there is a difference in the constitution of the clinker from these various raw mixes, it is not sufficient to change materially the physical properties.

Chemical Analyses (Insoluble). The chemical analyses of the clinker "A," "B" and "C," obtained from the corresponding mixes when burned at 1350° are:

	"A"	"B"	"C"
SiO_2	23.51	19.84	23.54
Al_2O_3	7.58	7.36	6.00
Fe_2O_3	2.94	3.16	1.83
CaO	64.56	67.81	67.59
MgO	1.60	1.76	1.16
	100.19	99.93	100.12

The analyses of the clinker burned at the other temperatures were not made. The raw material for all burns was mixed at the same time and consequently the clinker would analyse the same except possibly for the lower temperatures when quite likely the alkali was not as completely driven off as at the higher temperatures.


Trans. Am. Cer. Soc. Vol. XV Fig. 1. Bates
Compressive Strengths 1:3 Mortars
Lbs per Sq. In.
A
1450°
1350°
1400°
1300°
1200°
1100°
3000
2000
1000
0
Lbs. per Sq. In.
1
7
28
90
Age in Days

The amount of insoluble material (insoluble in 1.035 HCl) is a matter which seems to concern many. However, Cobb[3] has pointed out that mixes of silica, alumina and lime, when burned at 1250°, give no insoluble material. This temperature would in the great majority of cases give underburned clinker, so that the absence of "insoluble" would not necessarily show proper burning. In the present investigation the "insoluble" at 1100° and 1200° was determined and found as follows:

	"A"	"B"	"C"
degree	*percent*	*percent*	*percent*
1100	0.45	6.90	6.98
1200	0.26	0.13	0.10

As at 1200° the amount had been reduced to a negligible quantity, which indeed was largely introduced by the grinding of the burned material in porcelain jars with pebbles; it was not determined in the higher burned material. While the raw material was ground to a fineness of 85 percent through a 200 mesh sieve, which is almost 15 percent higher than that used in commercial practice, it does appear that a little too much emphasis is placed upon the percentage of "insoluble" as a criterion of the degree of burning.

Petrographic Analyses. In making the petrographic analyses the data and methods of the Geophysical Laboratory[4] have been used. These results are given in Table I. From this table the changes which have been brought about by the increase in temperature are clearly shown. It also shows that it would have been desirable to have made burns at 1150° and 1250°, since the changes between 1100° and 1200°, and 1200° and 1300°, were pronounced, the amount of β orthosilicate increasing from very small quantities to that of the most important constituent. As the examination was of the hard clinker, no mention is made of the "dust"—γ ortho-

[3] "The Syntheses of Complex Silicates," Colb, *Journal of the Society of Chemical Industry*, Vol. XXIX, 69–74, 250–59, 335–36, 399–404, 608–14, 799–802.

[4] "Preliminary Report on the Ternary System CaO-Al_2O_3–Fe_2O_3. A Study of the Constitution of Portland Cement Clinker, Shepherd-Rankin, *Journal of Industrial and Engineering Chemistry*, Vol. 3, No. 4.

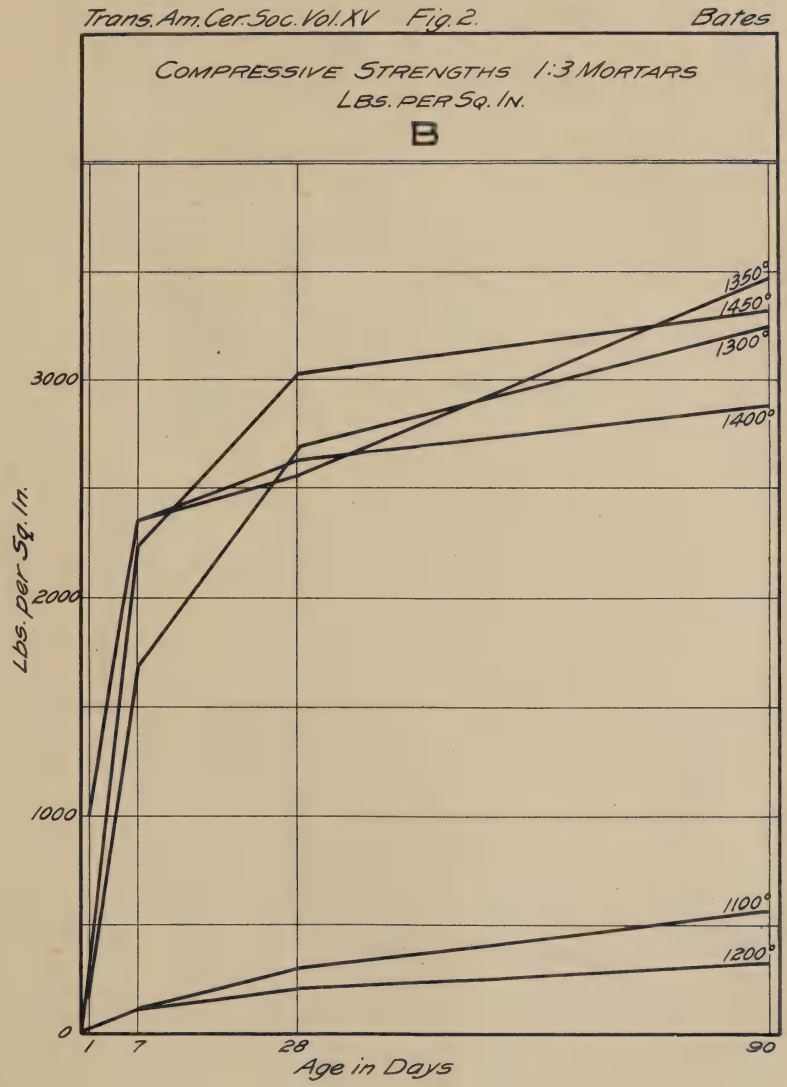

Trans. Am. Cer. Soc. Vol. XV Fig. 2. Bates
Compressive Strengths 1:3 Mortars
Lbs. per Sq. In.
B
1350°
1450°
1300°
1400°
1100°
1200°
3000
2000
1000
0
Lbs. per Sq. In.
1
7
28
90
Age in Days

TABLE I.—PETROGRAPHIC ANALYSES OF THE DIFFERENT BURNS

TEMP.	MIX	$\beta 2CaO.SiO_2$	$3CaO.SiO_2$	$3CaO.Al_2O_3$	$5CaO.3Al_2O_3$	FREE CaO	Fe_2O_3 COMPOUNDS	REMARKS
deg.								
1100	"A"	A little	None	None	Some	Predominating constituent	No "ferrite", no coloring of orthosilicate	Undecomposed clay, etc. present
	"B"	Very small amount	None	None	Some	Predominating constituent	As under "A"	Undecomposed clay, etc., present
	"C"	Very small amount	None	None	Some	Predominating constituent	As under "A"	Undecomposed clay, etc., present
1200	"A"	Important constituent	None	None	Some	Much less than in 1100° burn	Some "ferrite" also slightly coloring orthosilicate	Practically no undecomposed raw material
	"B"	Important constituent	None	None	Some	Much less than in 1100° burn but more than in "A" 1200°	As under "A" 1200°	As under "A" 1200°
	"C"	Some but not well developed	None	None	Some	Much less than in 1100° burn but more than "A" or "B" 1200°	Some "ferrite" has not entered the orthosilicate to a large extent	As under "A" 1200°

1300	"A"	Predominating constituent	A little noted	Only aluminate	None	Very little	No "ferrite"; Fe_3O_4; coloring orthosilicate and a slag	No undecomposed material
	"B"	Predominating constituent	A little noted	Only aluminate	None	Less than in "B" 1200°	"Ferrite"; no Fe_3O_4; coloring orthosilicate	No undecomposed material
	"C"	Predominating constituent	A little noted	More than of the $5CaO.3Al_2O_3$	Some	Less than in "C" 1200°	As under "B" 1300°	No undecomposed material
1350	"A"	Predominating constituent	More than in 1300° burn	Only aluminate	None	None	Fe_3O_4; coloring orthosilicate and a glass	
	"B"	Predominating constituent	A little	Only aluminate	None	Still as much as in "B" 1300°	Coloring orthosilicate and as a slag	
	"C"	Predominating constituent	A little	More than the $5CaO.3Al_2O_3$	Some	Still considerable	"Ferrite" and coloring orthosilicate	
1400	"A"	Predominating constituent	Possibly more than in "A" 1350°	Only aluminate	None	None	No "ferrite"; as a slag and coloring orthosilicate	
	"B"	Predominating constituent	More than in "B" 1350°	Only aluminate	None	Still considerable	Slag; coloring orthosilicate and Fe_3O_4	

TABLE I.—PETROGRAPHIC ANALYSES OF THE DIFFERENT BURNS—Continued

TEMP.	MIX	$2CaO.SiO_2$	$3CaO.SiO_2$	$3CaO.Al_2O_3$	$5CaO.3Al_2O_3$	FREE CaO	Fe_2O_3 COMPOUNDS	REMARKS
1400	"C"	Predominating constituent	Some	Only aluminate	None	Very little	Slag and coloring orthosilicate	
1450	"A"	No apparent difference from "A" 1400°						
	"B"	Predominating constituent	More than in "B" 1400°	Only aluminate	None	A little less than in "B" 1400°	Coloring orthosilicate and a slag	
	"C"	With the exception of less free CaO and more $3CaO.SiO_2$, no apparent difference from "C" 1400°						
1500	"C"	Show α as well as β orthosilicate	Considerable	Only aluminate	None	None	Coloring orthosilicate and a glass	

silicate–which was present after the burning at some of the lower temperatures. Mix "A" dusted after burning at 1100°, but "B" and "C" did not; evidently because there had been little of the orthosilicate formed. After burning at 1200°, all dusted on the exterior; beyond this temperature dusting was absent. This phenomenon is noted in starting rotary kiln; at first the raw material forms round nodules of very slightly sintered material, These do not dust. With increasing temperature the color of these nodules deepens, and shrinkage is apparent; these then dust. With still further increase of temperature the dusting formation of the γ orthosilicate from the inversion of the β disappears. It would appear that the prevention of the dusting or inversion at the higher temperatures, was caused by the entering into the orthosilicate of some impurity as iron oxide. It is noticed in the table that below 1300° the β orthosilicate is colored by the iron but slightly, but it has dusted. Attention is called to the paper of the Geophysical Laboratory cited above, in regard to the effect of alumina and magnesia on the formation of $3CaO.SiO_2$.

The α $2CaO.SiO_2$ was noted in but mix "C" burned at 1500°.

The β' $2CaO.SiO_2$ was not noted in any case.

The amount of $3CaO.SiO_2$ increases regularly with increase of temperature in the case of mix "A" up to 1450°; and in the other cases up to an including the highest temperature reached.

In the burns made at 1100° and 1200°, there is no $3CaO.Al_2O_3$ present, the only aluminate being the $5CaO.3Al_2O_3$. Beyond 1200° the $5CaO.3Al_2O_3$ disappears in mixes "A" and "B" but persists in "C" until 1350° has been passed.

The free CaO decreases with increase in temperature, rapidly in mix "A," less rapidly in "C" but very slowly in "B." In considering this constituent the composition of the mixes must be remembered—mix "B" contained more CaO than "A" and less SiO_2 than "C;" in fact in order that all the CaO would be combined it would require almost all the SiO_2 to be combined as the $3CaO.SiO_2$.

A discussion of the effect of the different temperatures upon the iron oxide is difficult in view of the lack of fundamental data in regard to the compounds of these oxides. At 1100° it was impossible to definitely isolate any compounds not originally present in

the raw material. At 1200° a compound referred to as "Ferrite" was noticed; this is a dark red material of unknown composition and refractive index above 1.74; this at higher temperatures seem to disappear, forming a slag or glass. The coloring of the orthosilicate is noticed generally above 1100°. Magnetite is also noticed in several instances.

Appearance of Clinker. The changes in appearance, such as color, shrinkage, vitrification, etc., require some comment and are shown in Table II. The changes are clearly shown which take place with increase of temperature, and apparently in mix "A," normal clinker had been produced at 1300°. The physical tests seem to bear this statement out. With mix "B" normal clinker was produced at 1350°; but the physical tests show that even at 1450°, a satisfactory cement could not be produced; and this notwithstanding the fact that the clinker even at 1400° would be classed as distinctly overburned. With mix "C" normal clinker was produced at 1400°, and such was proved by the physical tests.

Specific Gravity. The specific gravity of the clinker ground (to a fineness shown in Table III) but not plastered is shown in Table III. This was determined by means of a pycnometer.

The results obtained may seem strange to some, yet their general character has been referred to by a number of investigators, including just lately Arlt;[5] and West[6] who gives a rather interesting paper on this subject. He concludes his paper as follows: "In conclusion, the words of Zwick (1879) may be well repeated. 'It therefore follows that the specific gravity is a doubtful criterion of the value of cement.'" While it may not be agreed with West and Zwick in their statement, yet it is noticeable that the gravity in some of the decidely underburned material is higher than that usually adopted as requisite for cement, namely: 3.10. This is the fact which caused West and Zwick to make their statement and is supported by the former with many results and references.

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[5] *Handbuch Der Mineralchemie,* Bd. 1. 6, 832, Doelter and others; Reference by Arlt to Meyers paper in *Tonindustrie Zeitung,* 28, 33.

[6] "The Specific Gravity of Portland Cement," West, *Concrete and Constructional Engineering,* January, 1913, p. 13.

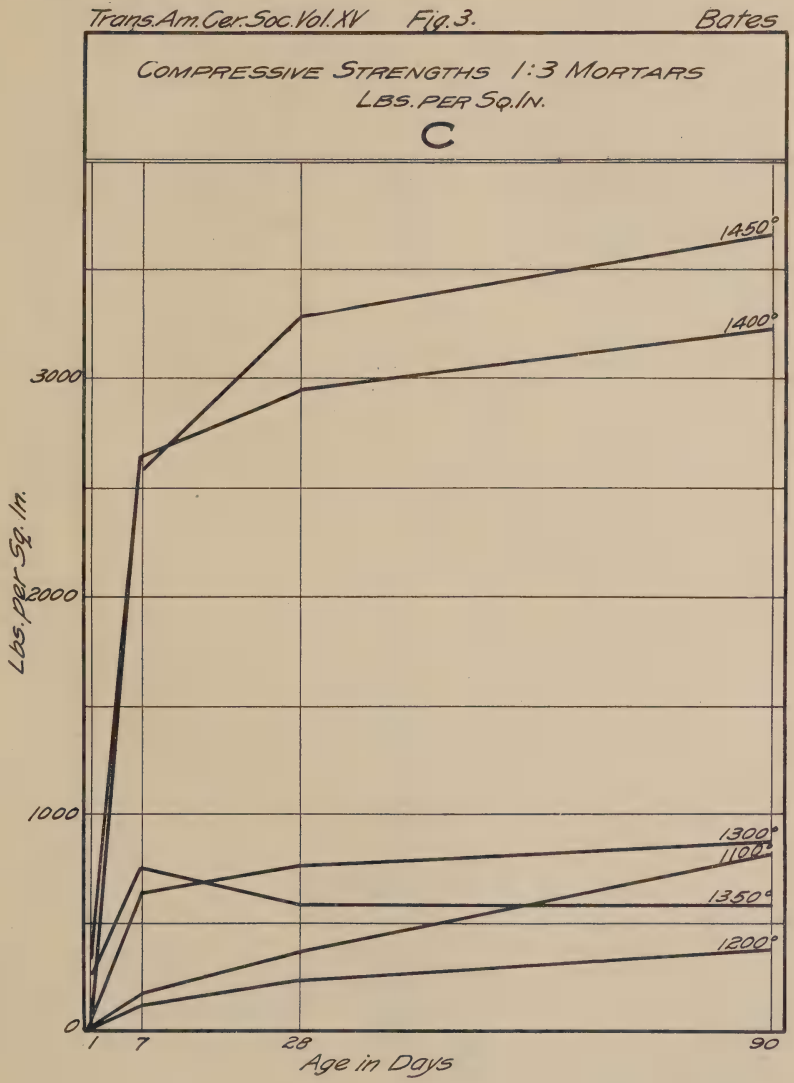

Trans. Am. Cer. Soc. Vol. XV Fig. 3. Bates
COMPRESSIVE STRENGTHS 1:3 MORTARS
LBS. PER SQ. IN.
C
1450°
1400°
1300°
1100°
1350°
1200°
3000
2000
1000
0
Lbs. per Sq. In.
1
7
28
90
Age in Days

TABLE II—GENERAL APPEARANCE OF THE CLINKER

"A"

TEMPERATURE	COLOR	SHRINKAGE	VITRIFICATION	GENERAL
Deg. C.				
1100	Dark gray	None	None	Soft. Air slaked in 84 hours
1200	Greenish gray	None	None	Rather hard. Air slaked in one month
1300	Greenish black	Some	"Incipient"	Appearance of normal clinker
1350	Greenish black. Very dark on exterior	Very marked	Very vitreous	"Overburned"
1400	Greenish black. Lighter on interior	Maximum	Very vitreous	"Overburned"
1450	Black on exterior. Brown on interior	About as at 1400°	Almost glassy	"Overburned"
		"B"		
1100	Buff	None	None	Soft. Air slaked in 48 hours
1200	Gray	None	None	Hard. Air slaked in one week
1300	Greenish black	Very slight	Barely apparent	Appearance of slightly under burned clinker
1350	Greenish black. Darker exterior	Marked	Vitreous	Normal clinker
1400	Greenish black. lighter on interior	Maximum	Very vitreous	"Overburned"
1450	Black on exterior. Brown on interior	Almost as at 1400°	Very vitreous	"Overburned"

		"C"		
1100	Pale buff	None	None	Very soft. Air slaked in 48 hours
1200	Dark gray buff	None	None	Soft. Air slaked in 72 hours
1300	Greenish gray	None	None	Much underburned
1350	Greenish gray	Very slight	None	Slightly underburned
1400	Light greenish to black	Marked	"Incipient"	Normal clinker
1450	Greenish black	Marked	Distinct, but rather porous	Normal clinker
1500	Greenish black	Enlarged considerably	Very vesicular	Swollen and cracked

TABLE III.—SHOWING SPECIFIC GRAVITY AND FINENESS OF THE GROUND CLINKER MADE FROM THE VARIOUS BURNS

TEMPERATURE	"A"			"B"			"C"		
	SPECIFIC GRAVITY	FINENESS Percentage retained on sieve		SPECIFIC GRAVITY	FINENESS Percentage retained on sieve		SPECIFIC GRAVITY	FINENESS Percentage retained on sieve	
		100	200		100	200		100	200
deg.									
1100	2.968	1.4	10.8	3.058	0.0	2.6	2.952	2.2	11.1
1200	3.127	2.4	21.4	3.191	1.0	11.1	3.098	0.4	12.2
1300	3.145	1.0	19.4	3.121	0.4	19.4	3.209	0.4	20.8
1350	3.227	0.4	12.4	3.132	2.8	20.8	3.250	1.0	19.4
1400	3.205	0.4	21.2	3.120	0.9	18.6	3.324	0.2	13.6
1450	3.141	0.6	16.2	3.126	3.8	24.0	3.258	0.6	18.6
1500							3.134	0.2	21.4

The fact that with increased temperature of burning, the gravity may fall off, has also been noticed by both Arlt and West; both again give the results of investigators substantiating this fact in their paper.

The percentage of water needed to give a normal consistency—as determined by the Ball method and the time of set determined by the Gilmore needle, are shown in Table IV for the ground clinker without any plaster and with 1, 2 and 3 percent plaster (the plaster used was commercially known as potters' plaster). The effect of steam—the ordinary steam test for soundness—is also shown for the pats made from the material containing 3 percent plaster.

Until some more accurate methods for the consistency and time of set, than the ones used or any others proposed, have been adopted, any fine distinction or close agreement between results cannot be secured. This applies particularly to cement containing no or small amounts of plaster. Such material lacks plasticity to such a degree that it is not only very difficult to handle, but it is also difficult to make tests with it, which tests have been devised for well-plastered and consequently plastic cements.

It is noticeable however that invariably the addition of 1 percent plaster makes the cement more quick setting than none; 2 percent begins to show the true purpose of the plaster—that of a "regulator" and not necessarily a "retarder" of the set, while the 3 percent shows this to good advantage and brings the set, except in the burns at abnormal temperatures, to a satisfactory time—acting as an "accelerator" in the originally slow setting and a "retarder" in the quick setting cements.

The percentage of water required for the normal consistency, decreases with the addition of plaster to a slight extent, and with increase of temperature of burning to a decided extent.

The soundness could have been predicted from the petrographic analyses. The amount of free CaO noticed then was sufficient to foretell the results of this test. The appearance of the clinker from mix "B" at 1400° and 1450° would not have led to such a prediction however, as it was extremely well-vitrified as noted before.

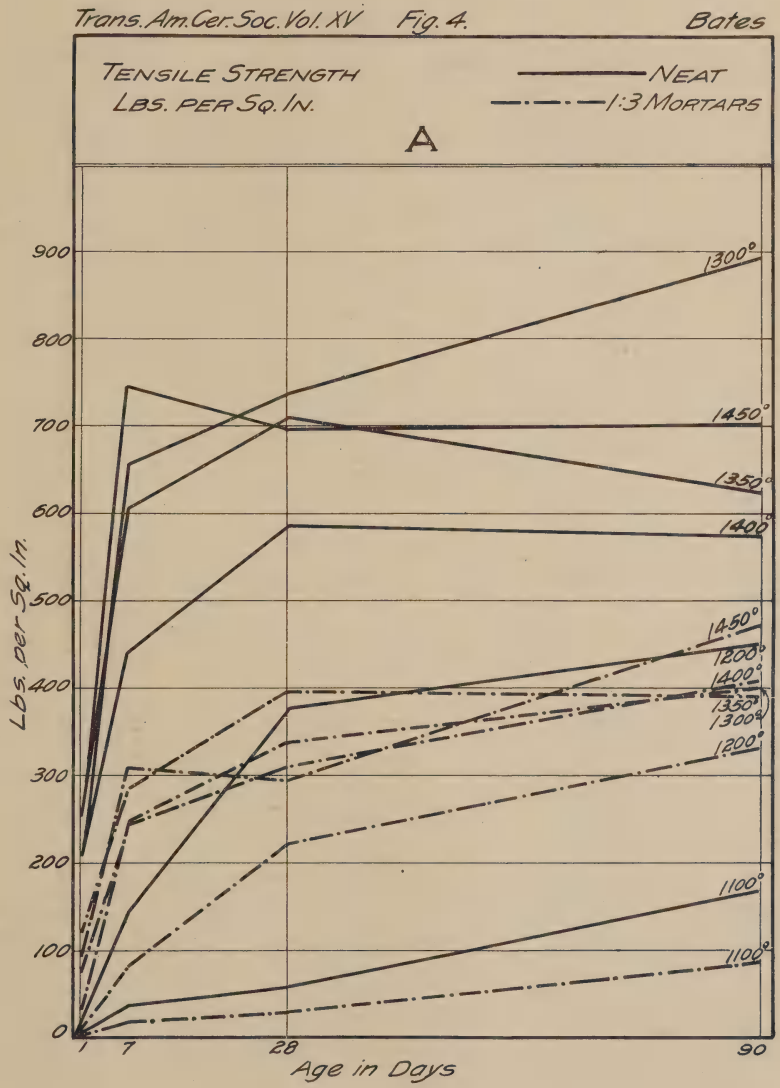

Trans. Am. Cer. Soc. Vol. XV Fig. 4. Bates
Tensile Strength
Lbs. per Sq. In.
Neat
1:3 Mortars
A
900
800
700
600
500
400
300
200
100
0
Lbs. per Sq. In.
1300°
1450°
1350°
1400°
1450°
1200°
1400°
1350°
1300°
1200°
1100°
1100°
1
7
28
90
Age in Days

TABLE IV.—CONSISTENCY AND TIME OF SET WITH 0, 1, 2 AND 3 PERCENT PLASTER. SOUNDNESS WITH 3 PERCENT PLASTER.

MIX	TEMPERATURE	PERCENT PLASTER												SOUNDNESS
		0 Percent			1 Percent			2 Percent			3 Percent			
		Set		Per cent	Set		Per cent	Set		Per cent	Set		Per cent	
		Initial	Final	H_2O	Initial	Final	H_2O	Initial	Final	H_2O	Initial	Final	H_2O	
	degrees	H. M.	H. M.		H. M.	H. M.		H. M.	H. M.		H. M.	H. M.		
"A"	1100	Slacked		35.0	6	10	32.5	7	11	32.5	27	60	32.5	Disintegrated before placed in steam
	1200	23	10–21*	30.5	19	9–18*	30.5	1 25	9–18*	31.0	4 20	15 50	29.0	Disintegrated
	1300	2 30	8 45	21.0	4 30	13 00	22.0	5 00	13 00	22.0	4 50	11 30	22.0	OK
	1350	3 00	22 30	28.0	11	9 15	28.0	4 25	8 00	25.0	5 15	8 20	25.0	OK
	1400	20	14–22*	24.0	4	9 30	25.0	3	5 23	24.0	20	8 50	24.0	OK
	1450	1 45	22 00	29.5	7	8 50	26.0	4	4 45	24.0	3 00	6 00	22.5	OK
"B"	1100	Slacked		50.0	Slacked		50.0	Slacked		45.0	Slacked		45.0	
	1200	Slacked		37.0	12	15	37.0	1 40	6 40 Cracked	37.0	35	4 30 Cracked	38.0	Disintegrated
	1300	9 00	22 00	28.0	6 15	13 00	27.0	5 30	12 30	26.0	4 50	11 40	26.0	Disintegrated
	1350	4 50	22 40	24.0	24	8 40	23.0	4 20	8 00	21.5	3 35	6 33	21.5	Disintregated
	1400	1 15	14–22*	25.0	20	11 15	25.0	1 45	7 15	25.0	1 50	6 20	25.0	Disintegrated
	1450	4 50	21 40	24.0	28	10 00	23.0	4 40	9 05	23.0	4 00	7 30	22.0	Disintegrated

"C"	1100	Slacked		50.0	Slacked		50.0	Slacked		50.0	Slacked		50.0		
	1200	Slacked		40.0	Slacked		40.5	Slacked.		43.0	Slacked		44.0		
	1300	2 30	15–23*	30.0	23	14–22*	30.5	8 15	22 00	29.5	9 00	20 20	27.5	Disintegrated	
	1350	1 15	12–21*	29.0	28	12–20*	29.0	8 40	20 30	29.0	8 55	20 55	29.0	Disintegrated	
	1400	2 45	7 00	25.0	1 15	9 20	23.0	3 30	Missed	23.0	3 50	7 30	23.0	OK	
	1450	9 25	15–22*	24.0	7	12 30	24.0	5 35	20 00	24.0	4 50	9 00	24.0	OK	
	1500	9 15	23 45	26.0	6 00	10 50	25.0	6 10	22 00	24.0	4 50	23 40	24.0	OK	

* Denotes set was between first and last time given.

Strength of Briquettes and Cubes. In Table V is shown the tensile strength of neat and 1 : 3 Standard Ottawa sand briquettes and compressive strength of 1 : 3 sand cubes. These results are shown graphically in Figures 1 to 6. These results are the average of three briquettes or cubes at 7, 28 and 90-day periods. In a number of cases is shown also the strength at twenty-four hours, when it was apparent that the specimens would have sufficient strength to make a test at this early period. The results are also given showing the effect of heating under 300 pounds pressure in an atmosphere of steam ("Autoclave Test"), starting with atmospheric pressure and increasing to 300 pounds in one and one-half hours and holding there for one-half hour longer. This heating was done at the end of twenty-four hours with the higher strength cements and at the end of seven days with the weaker ones.

In this table it is shown that there is apparently a temperature beyond which not sufficient strength is gained by further increase of the temperature to justify it.

It is readily seen how little is gained by burning "A" or "B" beyond 1300° and "C" beyond 1400°. It is also seen that the temperature of proper burning is within a comparatively narrow range, though to have shown this a little more clearly, more burns should have been made—since it is noticed that at 1200° both "A" and "B" were decidedly underburned and gave very low strength, yet at 1300° both show strength but little below the maximum. The same is noticed with "C" at the temperatures of 1350° and 1400°.

The results of the "Autoclave" test are interesting, but whether it shows anything beyond the ordinary "Soundness" test is questionable. Those burns which show disintegration in the latter, also show disintegration in the autoclave. In several cases it is noticed that the neat briquettes show a falling off in strength between the 7 and 28-day period (though the mortar specimens still show an increase) yet the autoclave does not show results which would lead one to expect this, showing on the other hand a very satisfactory gain. In one case "A 1400°" the autocalve shows a loss with the neat specimen, yet all specimens stored in water show very satisfactory gains.

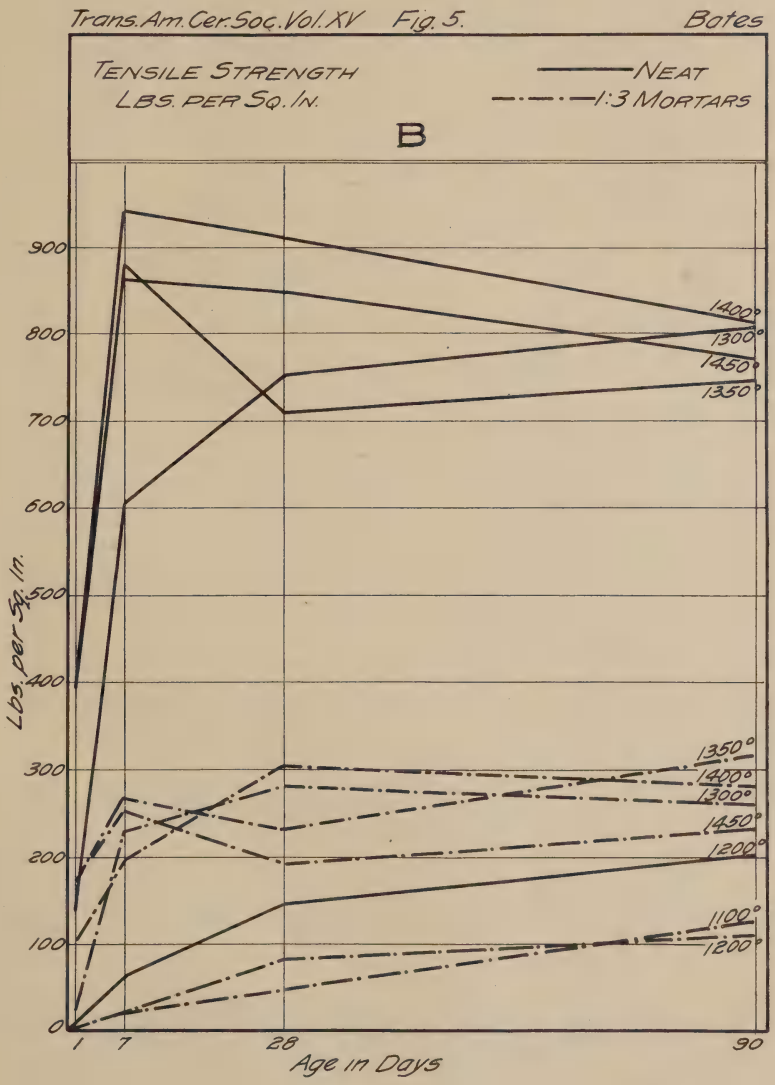
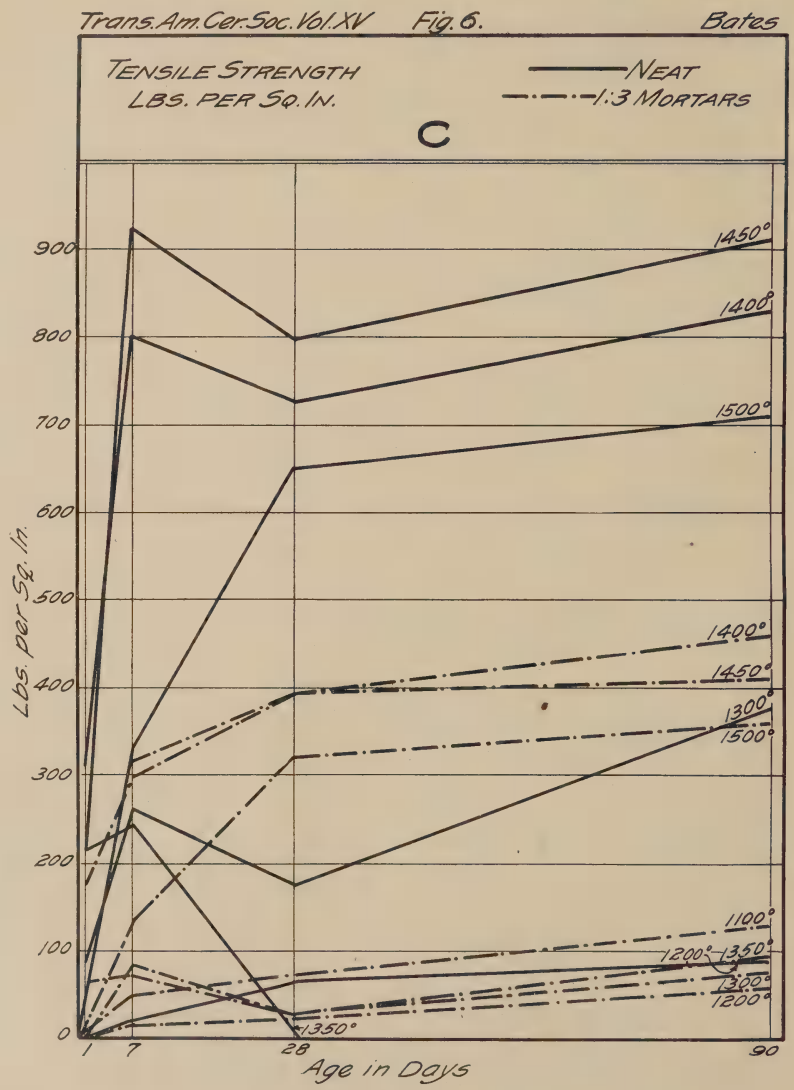

Trans. Am. Cer. Soc. Vol. XV Fig. 5. Bates
TENSILE STRENGTH
LBS. PER SQ. IN.
NEAT
1:3 MORTARS
B
900
800
700
600
500
400
300
200
100
0
Lbs. per Sq. In.
1400°
1300°
1450°
1350°
1350°
1400°
1300°
1450°
1200°
1100°
1200°
1
7
28
90
Age in Days

TABLE V—TENSILE STRENGTH OF NEAT CEMENTS IN POUNDS PER SQUARE INCH. TENSILE AND COMPRESSIVE STRENGTH OF MORTARS IN POUNDS PER SQUARE INCH.

TEMPERATURE	PERIOD	"A"			"B"			"C"		
		Neat	Tension 1:3 Mortar	Compression 1:3 Mortar	Neat	Tension 1:3 Mortar	Compression 1:3 Mortar	Neat	Tension 1:3 Mortar	Compression 1:3 Mortar
degrees										
1100	7 days.....	37	16	61	D*	21	120	D	50	189
	Autoclave.	D	D	D	...	39	133	...	49	396
	28 days....	59	29	94	D	46	305	D	71	385
	90 days....	167	86	410	...	125	579	...	130	813
1200	7 days.....	143	78	408	61	19	117	20	14	127
	Autoclave.	D	D	D	D	D	D	D	D	D
	28 days....	375	220	1178	146	81	204	65	22	231
	90 days....	448	333	1698	201	109	329	88	55	392
1300	24 hours...	224	36	273	139	22	146	85	Not made	...
	Autoclave.	268	125	1179	D	D	D	D	Not made	...
	7 days....	653	248	1582	605	226	1679	261	84	624
	28 days....	736	335	2542	757	279	2675	174	25	762
	90 days....	893	398	2566	810	258	3254	373	78	865
1350	24 hours...	268	122	621	402	172	1011	215	63	264
	Autoclave.	293	156	1607	D	D	D	D	D	D
	7 days....	605	282	2244	880	269	2375	246	74	763
	28 days....	710	396	2159	710	234	2541	D	26	594
	90 days....	621	389	3425	748	316	3484	D	92	595
1400	24 hours...	211	74	502	396	105	1011	308	171	Not made
	Autoclave.	192	99	638	D	D	D	455	160	Not made
	7 days....	436	244	1711	941	195	2388	800	299	2641
	28 days....	586	312	2392	910	303	2635	724	393	2942
	90 days....	571	403	3416	813	280	2890	828	460	3213

1450	24 hours...	252	90	390	Not made	173	Not made	224	68	313
	Autoclave.	396	137	1285	...	D	...	441	158	1184
	7 days....	746	307	2872	861	254	2274	923	315	2568
	28 days....	694	291	2658	849	191	3026	794	395	3284
	90 days....	700	471	3478	771	234	3330	911	410	3650
1500	7 days....	...	...	...	...	...	...	327	135	Not made
	28 days....	...	...	...	...	...	...	650	319	Not made
	90 days....	...	...	...	...	...	...	708	359	Not made

*D = Disintegrated.


Trans. Am. Cer. Soc. Vol. XV Fig. 6. Bates
TENSILE STRENGTH
LBS. PER SQ. IN.
NEAT
1:3 MORTARS
C
Lbs. per Sq. In.
0
100
200
300
400
500
600
700
800
900
1
7
28
90
Age in Days
1450°
1400°
1500°
1400°
1450°
1300°
1500°
1100°
1200°
1350°
1300°
1200°
1350°

Résumé. It has been shown that with increase of temperature, there is an increase in the amount of $3CaO.SiO_2$. That the condition of the iron oxide changes with increase of temperature—at a temperature a little below that necessary for proper burning, it enters into the orthosilicate coloring it brown and apparently preventing the inversion of the β form of that silicate to the γ on cooling and thus preventing the "dusting." That the alumina tends to pass into the $3CaO_2Al_2O_3$ form.

2. Investigation of the tables showing the results of the petrographic analyses and strength show:

a. That at early periods, at least, different raw materials give cements having very clearly the same physical properties and the same constituents. Whether these constituents are present in the same amounts has not been determined, though the indications are that any difference in these amounts has not been sufficient to make itself evident in the physical properties. Difference in composition, however, would inevitably demand some difference in the amounts of the constituents.

b. It has not been shown how an increase in the amount of $3CaO.SiO_2$ has affected the strength, since there has been also a change in the amount of $3CaO.Al_2O_3$ and free CaO. The combined effect of these changes has however been very slight, since there has been but slight change in strength beyond the temperature at which satisfactory material was first obtained.

c. The α orthosilicate was noticed only in burn "C 1500°." It is noticed that very low strength was obtained in this case, especially at seven days. The data is however too insufficient to allow the drawing of any conclusion from it.

3. While not of practical value, yet there is need of more work to show the relation between the specific gravity, temperature of burning and constitution. While there has been quite a little work done showing the relation between the two former, yet more accurate work is needed, and attempts made to correlate these with the constitution.

In conclusion, acknowledgments are due Messrs. Klein, Gates and Flaherty for assistance in preparing the mixes, making examinations and tests of the finished cement.

THE SUCCESSFUL OPERATION OF A CONTINUOUS KILN FIRED BY PRODUCER GAS

BY S. GEIJSBEEK, PORTLAND, OREGON

It cannot be said in favor of the American producer gas fired, continuous kilns that they have been a great success so far, notwithstanding the fact that this method of firing clay products has been in successful operation in European countries for over a quarter of a century. It has been, of late, the privilege of the writer to look into this matter carefully and study the different systems used in producer gas firing and to make comparisons between American and European methods of burning clay products in producer gas fired continuous kilns. The writer has been unable so far to compile all data thus gathered, and will for the present give only a few short notes in connection with the principal ideas.

Producer gas as applied to industrial furnaces has many advantages over other fuels. It also has many disadvantages. We have found, in our experiences with gas producers, that to obtain proper results with this fuel in a continuous kiln for burning clay products is a problem entirely distinct from that of the successful operation of the gas producers proper. The producer gas fired continuous kilns are a success if the application of the producer gas is brought about in the right manner and by the right methods. If the producer gas is applied along the same principles as used with solid or gaseous fuels in downdraft kilns, we do not obtain the regenerative principle of firing which is so essential in producer gas firing; and unless we apply this principle, any attempt to burn clay products with producer gas will fail. This principle of regenerative firing is not a new one. It was already recognized early in the last century and was patented in 1816 by Robert Stirling, a Scotch clergyman. He used this in furnace work and is considered the actual originator of the regenerative furnace. The work was carried on in England, and Ericson made some improvements in 1833. Later in 1853 Gorman obtained a new patent on the recuperative principle of firing. Frederick Siemens also obtained a patent on this principle in 1856. Smaller improvements have been made from time to time,

but the Siemens recuperative gas firing principle is still the best in use to-day in all industries.[1]

The air for burning producer gas should be heated before it is mixed with the gas in order to produce the best results and to work the most economically. This can be done in two ways, especially if we have waste heat gases at our disposal for that purpose. One of these methods is called "regeneration" and is used commonly in metallurgy, and the other method is named "recuperation" and is mostly used in furnace work. Regeneration is done by first heating a system of checker brick work with the waste heat gases, and then passing fresh air to be heated over this same brickwork. This system has not been used to any extent in clay plants. The principle of recuperation as employed in furnace work is as follows: the hot waste gases from the furnace are passed over individual pipes through which fresh air used for combustion flows, and the waste gases transmit thereby their heat to this fresh air, and this becomes heated.

The mistaken idea abroad is that there is a similarity between different kinds of gases, but this is far from the case, and producer gas will have to be handled differently from natural gas or gas generated from coal or other fuel in ordinary furnaces.

A fact learned by experience with producer gas fired kiln is that the higher the temperature, the more uniform and the more economical the results will be of producer gas firing. C. E. Ramsden[2] states that there is no doubt that the continuous gas fired kiln is very successful for burning refractory goods, but it has certainly not been adopted to any extent for medium temperatures.

The methods of making producer gas from solid or liquid fuels is not a point on which much trouble is experienced. Any gas producer built along the right principles, and gasifying with satisfactory results will do the work. We have several firms in this country who have built and equipped good gas producers, and the great strides which have been made in the producer gas power plants show that the American gas producers have given good results. In 1911 there were in operation between 900 and 1000 producer gas power plants, ranging in size from 15 horsepower to several thou-

[1] J. Dunnachie, *Transactions English Ceramic Society*, Vol. VIII, p. 81.
[2] Cyril E. Ramsden, *Transactions English Ceramic Society*, Vol. III, p. 105.

sand horsepower, the total horsepower produced by these plants amounting to over 163,000 horsepower. In addition to this, we have the blast furnace and coke oven gas power plants with 339,280 horsepower.[3] It can readily be judged from these facts that the gas producer problem is applying itself more and more to all industries.

If the application of producer gas to power engines has been successfully demonstrated and put into practical use, there is no reason why the application of producer gas to furnace work, and to burning clay products should not be solved successfully also. In practice it has been found, however, that in spite of a good gas producer plant or a producer plant in good working order, good results have not always been obtained in the burning of clay products. It goes to emphasize the fact that there is a distinct difference between making gas in a gas producer, and applying the same to burning clay products. In the burning of clay products, the successful method of applying the gas and its mixing with air in order to obtain the best results are the factors of importance, and it is right here that most systems now in use in this country are either total or partial failures.

We find upon investigation that we must apply the system of regeneration or recuperation and must bear in mind that waste gases and such gases as are completely burned, can never produce heat again. They will be able to give off their heat by radiation, but this heat has no effect on the combustion of the producer gas, with which they are generally mixed, and it is right here that the present existing producer gas fired continuous kiln systems fail. They are designed principally to use the waste gases from the burning chamber to heat up the next chambers ahead of the fire, and do not attempt, nor have any provision made to regenerate or recuperate the air to be mixed with the producer gas. In the principle of using waste heat to advantage, they are well designed and are giving very satisfactory results. There is, however, a vast difference between the application of waste heat and the process of producer gas combustion.

In the regular way of firing clay products with fire boxes, we

[3] R. H. Fernald, Bulletin 55, Bureau of Mines, "The Commercial Trend of the Producer Gas Power Plant in the United States."

admit the air for combustion, either as cold air direct or somewhat preheated according to the method employed; but in either case the distance the air has to travel is short, and the air is constantly changing. In a continuous chamber kiln the process is different. The air for combustion passes through four and sometimes five chambers, sometimes in a straight flue arrangement and in other systems in an up and down arrangement, which lengthens the course of the air still more. The air comes to the first chamber behind the fire and passes into the burning chamber, where it is mixed with the fuel or gases to produce proper combustion. In a continuous kiln fired with coal from the top, there is always an opportunity for fresh air to rush inside the kiln through these firing holes but in a producer gas fired continuous kiln there is no such opportunity. If the rate of inrush of cold air at the last cooling chamber is great, it will be quite less by the time the air arrives at the firing chamber for we find that air expands as it gets heated, and in fact it expands about 4.82 times in volume at a temperature of about 2000°. The quantity of oxygen, therefore, is far less in this heated air than in the cold air in the same amount of volume.

Continuous kilns are operated either by mechanical fan equipment or large chimneys, and the draft created by either of these systems is the draft of the whole system. Experience has proven that this draft decreases as the chambers are heated up and is the smallest at the burning and just cooling chamber while it increases again as the chambers are cooled down. So that with 15 mm. draft at the stack or fan, the burning chamber will have only 1 mm. and the just cooling chamber will have only 0.5 mm. draft, while the last cooling chamber will show again about 10 mm draft. Of course, these figures depend upon the length of the duct and the size of the fan or stack. These were taken, however, on a working gas producer kiln. The expansion of the air at high temperature mentioned before is responsible for these facts. It has also been observed that by lowering the fan draft, pressure could be produced on the burning chamber. If there is little draft in the first chamber behind the fire, there can be only very little movement of air, and consequently only very little air can be available for the combustion of the gases in the burning chamber. We find, therefore, a lack of proper combustion. In European practice this is mostly

overcome by admitting fresh air direct before the burning chamber, and in other instances by an interchangeable set of dampers, so that more draft can be created at the burning chamber.

If gas and air are burned without pressure, we obtain the same results as in an ordinary gas flame, which is certainly not hot enough to burn clay products. However, if we increase the pressure on both, and put in a blast for the air and admit gas under pressure, we obtain a flame which will attain high temperature. This same principle applies to the producer gas in a continuous kiln. It does not have any air supplied under pressure, and consequently the results of the combustion are low in temperature.

Nisbet Latta[4] states that it has been noted from experiments that in a furnace where producer gas and air were admitted under atmospheric pressure, they have given a resultant furnace temperature of about 1600° F; their admission under pressure of 1 inch (25 mm.) increases this furnace temperature to about 2000° F; while with an increase in pressure of both elements to about 2 inches (50 mm.) they gave a corresponding increase of temperature to 2400° F.

The principal idea when using producer gas in continuous kilns, is to bring the producer gas into contact with heated air in order to get higher efficiency of combustion. The gas, as used in such kilns, will need a great deal more air to burn than is ordinarily assumed since the heated chamber to be burned has already attained a very high temperature and the carbon of the producer gas will be entirely oxidized at that temperature. There is also a limit to the oxidation of carbon. H. Ernst[5] has found that the oxidation of carbon begins at 752° F. and that carbon dioxide (CO_2) is formed as the main product with only a small quantity of CO whether the air was admitted in large or small quantities. He further found when the rate of combustion increases and the temperature was raised to about 1300° F. that the chief product was still CO_2 even if the waste gases contained 20 percent of CO_2 by volume. However, above that temperature the proportion of CO increased rapidly until 1800° F. was reached when CO was exclusively produced.

We must further consider that a kiln which is just burned off, and even cooled for twelve or fourteen hours, will give off enough

[4] Nisbet Latta, *American Gas Producer Practice*, p. 398.
[5] H. Ernst, *Engineering Magazine*, April, 1893.

waste gases which are still contained in the hot bricks and in the walls of the kiln to make the preheated air far less effective than if new fresh air was heated up and mixed with the gases of the producer.

In European practice with producer gas fired continuous kilns, there is more attention paid to the proper air circulation than to the producer gas. Another fact, we find in European practice is that in nearly all cases the gas is taken from the producer to the kilns and admitted in the kilns by underground flues and bottom inlets. This is done in order to harmonize the properties of the producer gas with the effects to be obtained. Producer gas, being lighter than air, will more quickly mix with air and will more readily ascend into the kiln from a bottom flue supply than if carried overhead and then forced down into the kilns, there to be mixed with air as is the practice in the American constructed gas producer continuous kilns.

The best results obtained in firing downdraft kilns with solid fuel, natural gas or fuel oil are where we have complete control of the fuel, the air and the draft, and unless these three agents are under control we cannot expect good results. The question is therefore, asked if in producer gas fired kilns these essential points have been taken into consideration, and we must regretfully admit that they have not. Some kilns try to control the gas, others the draft, and none, as far as we know, in American practice have any control over the air. While draft and air are closely connected with each other, there is a great difference between controlling the air by means of the draft and admitting air at proper places and intervals, and using it as necessary without connection with the draft operating on the kiln.

Some of the conclusions of the study of gas producer fired continuous kilns in order to make the same work successfully we have arrived at is that: first, we will have to devise a system by which we can first recuperate or regenerate the air necessary for combustion and by which we have complete control of such preheated air second, that we must have complete control of the waste gases and the draft; and third, that we must have complete control over the gases of the gas producer proper before they are admitted to the kiln.

As stated at the outset of this paper, only a few of the principal ideas and differences have been brought up for the present. No data nor comparisons have been given of the actual fuel consumption nor of the many advantages and disadvantages of the large chambers mostly in use in American continuous kilns. All Continental continuous kilns have much smaller chambers than have been practiced in building here. Another point not touched upon is that European continuous kilns and, in fact, most kilns built abroad are designed for their special purposes and are built accordingly. A continuous kiln for burning common brick is a different proposition from a kiln built for burning fire clay products. The principle, as practiced in this country, to design and build a continuous kiln which will answer or all purposes and all kinds of clay products, for all local conditions and all different classes of fuel, is not approved in foreign countries.

All these conditions should be studied beforehand and taken care of, and the success of such a continuous kiln is bound to be obtained more quickly and at less cost. To build a kiln first and change it afterwards to suit the purpose of the clay products to be burned in it is certainly the wrong method of solving a complex problem. It is a long way from success, and such procedure spells failure from the very start. There are plenty of monuments scattered all over the country to substantiate the soundness of this principle.

It is the writer's opinion that continuous kilns fired with producer gas can be designed and built to work very successfully, and the few facts stated above will go a long ways to solve the problem. It is also possible to change the many kilns which have been built to make them work successfully if the fundamental principles of the application of producer gas are applied properly.

GRAPHIC GRANITES AS A SOURCE OF FELDSPAR[1]

BY ARTHUR S. WATTS

As the exposed deposits of pure feldspar in the United States are rapidly being worked out and the locating of new deposits of pure material is a matter of more or less uncertainty, it seems wise to seriously consider the available sources of feldspar which are not in the pure form but which contain no impurity which renders the feldspar unfit for ceramic uses. The most fruitful source of such investigation is the graphic granites or graphic pegmatites of the New England States. The pure feldspars of New England have been obtained from these pegmatite dikes, in which they occur as isolated lenses, and in their removal vast amounts of pegmatite rich in feldspar and containing little or no impurity, except quartz, was quarried but rejected at that time as waste. As the lenses of pure material were becoming exhausted, the operator began to work over these waste heaps and also the walls of the quarry adjoining the pure feldspar lenses, and he found there much material free from other impurity except quartz. This material was sorted, and the portion in which the quartz content did not exceed 10 or 15 percent was accepted and mixed with the pure feldspar. No serious difficulty resulted from the replacement of 5 or 10 percent of the feldspar by quartz, as this amount of variation in the ordinary pottery body might often occur through the use of material in which an excess of moisture existed.

However, each year the supply of available pure feldspar becomes less and also the portion of the graphic granites richest in feldspar are used, leaving us a poorer assortment from which to select. The result is that the feldspar from New England has gradually changed from a material deforming at cone 8 to one deforming at cone 9, or even cone 10. This change or hardening of the feldspar is not due to any change in the feldspar itself but merely to the increased amount of quartz which is ground with the feldspar.

Owing to the gradual hardening of the commercial grade of New England feldspars, many users have turned their attention to

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[1] By permission of the Director, United States Bureau of Mines.

other sources of supply, thus fortunately leaving the use of the New England feldspars to those manufacturers who found their use essential to the securing of proper color in their wares. This is especially true of the Maine feldspars, which are recognized as being of superior color to any other American feldspar except the North Carolina feldspars, the high price of which prohibits their use in many industries.

Graphic pegmatites or graphic granites, as they are generally termed, do not differ in their essential constituents from the ordinary pegmatite except that the quartz present is in a distinct crystalline form, as will be seen in the accompanying illustration, Plate 1. The remarkable similarity to Chinese lettering displayed by these quartz crystals has led to the application of the term "graphic granite" or "Schrift granit," as it is called in German literature.

The practical application of these graphic granites naturally depends upon the amount of impurity present; and it is worthy of note that when the feldspar and quartz are crystallized together in this graphic form, the amount of other minerals present is much less than in other forms of pegmatite or granite. Quartz being the chief associated mineral, its influence upon the deformation point of the feldspar is of chief importance to the ceramist.

Vogt[2] has offered the theory that in the graphic granites the quartz and feldspar are present in eutectic proportions. He presents as evidence the following analyses of graphic granites and their recalculation into feldspar and free quartz contents.

	NO. 1	NO. 2	NO. 3	NO. 4
SiO_2	74.04	74.00	73.82	74.47
Al_2O_3	14.44	14.31	14.44	15.13
CaO	0.33	0.39	0.35	0.72
K_2O	9.36	9.02	8.90	7.06
Na_2O	2.01	2.42	2.45	2.01
Feldspar	74.7	75.3	75.3	72.7
Free quartz	25.3	24.7	24.7	27.3

[2] *Die Silikatschmelz-lösungen*, von J. H. L. Vogt, 1904, pp. 117–128.

In conclusion he says, "When the potash feldspar is in excess the proportions of feldspar and quartz in graphic granites are absolutely constant or only very slight variable. . . .

"From this we conclude with absolute certainty that the graphic granite is a eutectic mixture and has a composition approaching 74 percent feldspar and 26 percent quartz."

J. J. H. Teall in *British Petrography* concludes that the graphic represents the eutectic between feldspar and quartz.

Plate 1

H. E. Johnson (*Geologiska föreningens förhandlinger*, Stockholm, Vol. 7, 1905, p. 119) concludes that the feldspar-quartz content in graphic granites has a definite ratio, dependent upon the type of feldspar present. When the feldspar is orthoclase, the molecular ratio of feldspar to quartz is 2:3. When the feldspar present is plagioclase, the molecular ratio is 1:2. When the feldspar present is albite, the molecular ratio is 1:3.

Bryden (Bull. Geol. Inst., Univ. Upsala, Vol. 7, 1904, p. 1–18) concluded from a study of many analyses that the type of feldspar present bears no definite relation to the feldspar-quartz ratio. He believes that a definite feldspar-quartz ratio does exist in most

graphic granites, but thinks it is not so simple as Vogt and Johnson imagine.

E. S. Bastion (Bull. 445, U. S. Geol. Survey, pp. 39–42 and 124–125) after considering the data and opinions of other investigators, compiled a table of mineral compositions of graphic granite in which he included not only all available foreign data but also the compositions of three Maine graphic granites. From a study of these he finds that even among graphic granites whose feldspars are almost identical in composition, there are considerable variations in the feldspar-quartz ratio.

The list of graphic granite compositions will be included in an enlarged list connected with this chapter.

The subject of chief interest to users of feldspar is the possible variation of graphic granites throughout a given district, both as regards ratio of feldspar to quartz and also as regards the chemical composition and physical behavior of the feldspar component of the graphic granites.

CHEMICAL COMPOSITION OF NEW ENGLAND GRAPHIC GRANITES

	A	B	C	1	2	3	4
SiO_2	73.89	74.34	74.53	73.89	73.92	72.76	71.00
Al_2O_3	14.33	14.45	14.26	13.75	14.26	15.47	16.31
CaO	trace	trace	trace	none	none	0.19	0.22
MgO	trace	trace	trace	none	none	none	none
BaO	none	none	none				
Fe_2O_3	0.16	0.14	0.16	0.26	0.30	*	*
K_2O	9.02	8.63	8.55	9.00	8.99	9.28	8.66
Na_2O	2.14	2.00	2.25	2.10	2.06	2.35	3.44
H_2O	0.33	trace	0.30	0.24	0.11	0.15	0.12

CALCULATED MINERAL COMPOSITION

	A	B	C	1	2	3	4
Potash feldspar	53.4	51.1	50.6	54.4	55.2	55.0	51.4
Soda feldspar	18.2	16.9	19.1	18.5	18.5	20.0	29.1
Lime feldspar						1.0	1.0
Free quartz	26.9	29.7	28.7	27.1	26.3	23.0	17.6
Other constituents	1.5	2.3	1.6	trace	trace	1.0	0.9
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Fe_2O_3 included with Al_2O_3.

A. Fine grained graphic granite (see illustration) from newly opened quarry of Maine Feldspar Company, east slope of Mt. Ararat, Topsham, Me., Bureau of Mines analysis.

B. Medium grained graphic granite (see illustration) from Wm. Willis' quarry, Cathance, Me., Bureau of Mines analysis.

C. Coarse grained graphic granite (see illustration) from Golding Sons Co. quarry, Georgetown peninsula, Me., Bureau of Mines analysis.

1. Coarse graphic granite, Fisher's quarry, Topsham, Me., United States Geological Survey analysis. Quartz layers about 1 inch across and feldspar layers about 4 inches across.

2. Moderately coarse graphic granite, Fisher's quarry, Topsham, Me., United States Geological Survey analysis. Quartz layers about 0.05 inch across and feldspar layers about 0.15 inch across.

3. Fine grained graphic granite from Kinkles' feldspar quarry, Bedford, Westchester County, N. Y., United States Geological Survey analysis. Quartz layers about 0.03 inch across and feldspar layers about 0.08 inch across.

4. Graphic granite from Andrews quarry, Portland, Conn. United States Geological Survey analysis. Quartz layers vary, but average not more than 0.02 inch across. The feldspar layers average not more than 0.05 inch across. Some areas of pure feldspar in the sample increase the feldspar content shown by the analysis above what a graphic granite of this fineness should yield.

Analyses Nos. 1, 2, 3 and 4 are from Bulletin 445, United States Geological Survey, p. 124.

A study of analyses A, B, C, 1 and 2, all of which are from the chief feldspar producing district of Maine, shows no greater difference in chemical composition than would be expected in samples taken from different portions of a single quarry. The maximum variation in potash content is 0.47 percent, and the maximum variation in soda content is 0.25 percent. The maximum variation in total alkali is only 0.53 percent. The maximum variation of alumina content is 0.70 percent and the maxiumm variation of silica content is 0.64 per cent. Calculation into their mineral constituents indicates a maximum variation in free silica content of only 3.4 percent.

From the foregoing it appears that the statement of Vogt regarding the ratio of feldspar and quartz seems to hold for Maine graphic granites.

A study of the calculated mineral compositions indicates no regularity between the variation in free quartz content and the

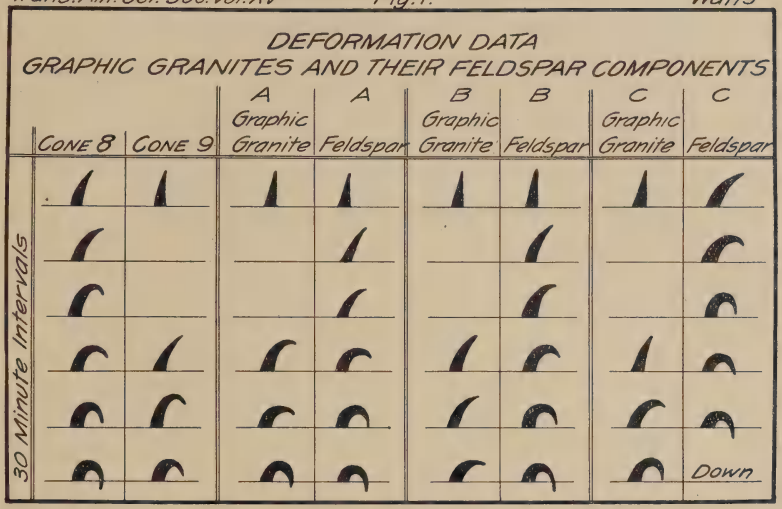
size of quartz particles. The next problem was to determine the relation between the pyrometric behavior of the graphic granites and of their feldspar constituents. For this study, three graphic granites, A, B and C, which grade from very fine to very coarse grain, were selected. The quartz content in all these is of the smoky quartz variety, and the feldspars are indicated by optical analyses to be microclines with small intergrowths of albite.

The three graphic granites were photographed (see photo) and then divided into equal parts, one portion of each being pulverized as pegmatite while an equal portion was carefully cleaned of all free quartz content and pulverized as pure feldspar. The pulverized material was all ground to pass a 200-mesh sieve in the dry state. A portion of each was mixed with a small amount of dextrine and molded in the plastic state into cones similar to standard pyrometric cones. These cones were tested as follows: (*a*) for the deformation temperatures and rates of the graphic granites as such; (*b*) for the deformation temperatures and rates of the pure feldspar components; (*c*) for the relation between the graphic granites and mixtures of their feldspar components with known amounts of pulverized quartz. The quartz used in this last test was quartz sand pulverized to pass 200-mesh sieve dry. The relative pyrometric behavior of the graphic granites and their feldspar components is shown in Figure 1.

A study of the diagram indicates that, at least in the case of these graphic granites of Maine, the deformation temperature lies well beyond that of their feldspar components. The first of the feldspar to commence deformation was C, followed within a few degrees by B and A feldspars. The feldspars all deform at about the temperature of cone 8. Feldspar C deforms slightly ahead of cone 8 and feldspars A and B deform slightly behind cone 8. The rate of deformation of the three feldspars varies slightly. Feldspar C which begins deforming first has the highest rate of deformation with feldspars A and B deforming together at the same rate as cone 8.

The three graphic granites of which these three feldspars formed a part do not deform until cone 9 and furthermore do not deform in the same order as the feldspars but follow the order of calculated free quartz content. Graphic granite A, which has a calculated

Trans. Am. Cer. Soc. Vol. XV Fig. 1. Watts



free quartz content of 25.8 percent, begins to deform noticeably ahead of the other two granites and completes deformation distinctly ahead of them. Graphic granites B and C carrying respectively 27.6 percent and 27.4 percent of free quartz begin to deform at the same temperature, but C deforms more quickly than B and completes deformation when B is not more than half deformed.

A study of the chemical analyses of these graphic granites discloses the fact that graphic granite C has the lowest Al_2O_3 content and the highest Na_2O content, both of which tend to favor rapid deformation in the pure feldspar; but the small free quartz excess contained in this graphic granite more than counteracts the effect of the more fusible feldspar and causes it to deform behind graphic granite A, which contains slightly less Na_2O and slightly more Al_2O_3 but which contains 1.6 percent less free quartz. Graphic granite B, which is the richest in free quartz and contains the highest percentage of Al_2O_3 and the lowest percentage of Na_2O, is the most refractory graphic granite, and its feldspar component is more refractory than that contained in either of the other two graphic granites.

Thus it is clear that a slight variation in composition may greatly change the temperature and rate of deformation of a graphic granite. It must be remembered, however, that the three graphic granites studied are so similar that in commercial operations the difference in pyrometric behavior would hardly be noticed.

The main point brought out by this study is the fact that graphic granites high in potash and low in soda and containing no lime, of which the graphic granites of Maine are examples, deform at temperatures distinctly higher than do their feldspar components. Hence they are not deformation eutectic mixtures of feldspar and quartz. Whether these graphic granites are true eutectic mixtures, in that the ratio of feldspar to quartz represents the saturation point of each in the other so that both may solidify at the same time, is a question which this study is not designed to prove.

The determination of the quartz content in the graphic granites by synthesis resulted as follows.

Graphic Granite "A," very fine grained. A block of this material was crushed and then cleaned as completely as possible of free quartz. The fact that the quartz present was of the smoky variety made its detection less difficult than would otherwise be the case. The pure feldspar was pulverized to pass 200-mesh sieve and mixed with increasing percentages of pulverized quartz in 5 to 35 percent amounts. The mixtures were molded into cones of standard dimensions. This series was placed on a fire clay slab, together with a specimen of the original graphic granite "A" and also a specimen of the pure feldspar "A." The pure feldspar deformed with cone 8. The graphic granite "A" deformed slightly above cone 8 and simultaneously with the mixture of feldspar "A" and 25 percent quartz. A comparison of this data with the calculated norm composition shows that the discrepancy is not very great.

Graphic Granite "B," medium size grains. A block of this material was crushed, cleaned and pulverized in the same manner as Graphic granite "A." Cones of the same feldspar and quartz percentage compositions were prepared and tested in a similar manner with specimens of pure feldspar "B" and graphic granite "B." Pure feldspar "B" deformed at cone 8. Graphic granite "B" deformed with the mixture of feldspar "B" and 30 percent

quartz and at the temperature of cone 9. A comparison of this data with the calculated norm composition indicates the discrepancy to be 2.4 percent as the calculated composition indicates 27.6 per cent free quartz.

Graphic Granite "C," coarse grained. A block of this material was prepared and tested in a manner similar in all respects to that followed with graphic granites "A and "B." Pure feldspar "C" deformed midway between cones 7 and 8. Graphic granite "C" deformed between cones 8 and 9, but nearer cone 9 temperature. It deformed with the mixture of feldspar "C" and 30 percent quartz. A comparison of this data with the calculated norm composition shows the synthetic mixture to be 2.6 percent high.

This method of determining the quartz content of a pulverized feldspar is shown to be perfectly practical within general limits, but cannot be depended upon for determinations closer than two or three percent. This discrepancy is possibly in part due to the fact that the quartz used in the synthetic mixtures was finer grained than the quartz contained in the ground graphic granite. This fact was proven by microscopic study of the fused cones, although the powdered materials were all thought before use to be of sufficiently uniform fineness.

In nature, graphic granite is a mixture of feldspar and quartz in intimate crystalline relation, but both exist as distinct minerals. These graphic granites must be reckoned as mixtures of feldspar and quartz, which fortunately are remarkably constant for graphic granites containing feldspars free from lime and high in potash and low in soda. If the user will recalculate the graphic granites into feldspar and quartz and introduce them as such, much of the difficulty arising from their use will be overcome.

There follows a list of graphic granites calculated into their mineral components as norms.[3]

[3] Bull. 491, U. S. G. S., "The Data of Geochemistry," pp. 404-406 inc.

GRAPHIC GRANITES.* CALCULATED INTO THEIR NORM COMPONENTS

LOCALITY	FELDSPAR CONTENT			FREE QUARTZ	REFERENCE
	POTASH FELDSPAR	SODA FELDSPAR	LIME FELDSPAR		
1. Hitterö	51.2	14.3	0.5	34.0	Bygden, No. 8
2. Skarpö	58.2	10.6	1.7	29.5	Bygden, No. 7
3. Cathance, Me.	51.1	16.9		27.6	Graphic granite B, this article
4. Georgetown, Me.	50.6	19.0		27.4	Graphic granite C, this article
5. Reade	48.1	20.5	4.1	27.3	Vogt, No. 4,
6. Topsham, Me.	54.4	18.5		27.1	Bull. 445, U. S. G. S. p. 124.
7. Topsham, Me.	55.2	18.5		26.3	Bull. 445, U. S. G. S. p. 124.
8. Topsham, Me.	53.4	18.2		25.8	Graphic granite A, this article
9. Voie, Arendel	55.1	17.9	1.6	25.3	Vogt, No. 1
10. Hitterö	52.0	21.5	1.8	24.7	Vogt, Nos. 2 and 3.
11. Arendel	48.9	25.8	1.8	23.5	Vogt, No. 5
12. Bedford, N. Y.	47.4	28.4	1.0	23.2	Bull. 445, U. S. G. S. p. 124
13. Elfkarleö	59.2	19.4	0.6	20.8	Bygden, No. 6
14. Portland, Conn.	51.2	29.2	0.2	17.4	Bull. 445, U. S. G. S. p. 124
15. Rödö	6.0	47.8	2.8	39.0	Bygden, No. 9
16. Ytterby	2.7	46.3	13.1	37.9	Bygden, No. 11
17. Eoje	8.5	51.9	7.9	31.7	Vogt, No. 6
18. Beef Island	3.8	55.5	22.4	18.3	Bygden, No. 12.

* This list with the exception of Nos. 3, 4, 8 and 14 is discussed by E. S. Bastin, Bull. 445, U. S. Geol. Sur., p. 41–2.

A study of the foregoing table discloses the fact that the ratio of potash feldspar to soda feldspar is generally greater than 2 : 1 and often reaches 3 : 1. Where soda feldspar is the prevailing type present, potash feldspar is present in very small amount only. The graphic granites 15, 16, 17 and 18, belong to a class entirely distinct from the remainder of the list. A fact worthy of note in the study of this list is the small variation in norm content of potash feldspar in Nos. 1 to 14 inclusive, with the exception of Nos. 2 and 13, the potash feldspar content is between 47.4 percent and 55.2 percent of the graphic granite, while the soda feldspar in the same series varies

from 10.6 percent to 29.2 percent. In the first fourteen numbers of the table, i.e., the graphic granites high in potash feldspar, only two numbers contain more than 27.6 percent free quartz and only two contain less than 23.2 percent. Thus 70 percent of the graphic granites studied contain free quartz in percentages between 23.2 and 27.6, or a variation of 4.4 percent.

DISCUSSION

Mr. Hope: I would like to ask what is considered the mixture of lowest melting point between feldspar and quartz? What is considered about the eutectic mixture?

Mr. Watts: Well, my work last year indicated that it was in the neighborhood of 10 percent of quartz to 90 percent feldspar; that is when the feldspar has a composition of about 12 percent of potash and 2 percent of soda, which is a very good average feldspar. While the feldspar begins to deform a little before the feldspar-quartz mixture, the rate of deformation of the feldspar-quartz mixture is so much more rapid, that, before the pure feldspar has reached the complete curve (come down to touch the plate, as we say) the feldspar-quartz mixture has also reached that point, making its period of deformation so much shorter than the pure feldspar that we may consider it a deformation eutectic.

Mr. Hope: Would you say then that the feldspar with 10 percent of quartz is softer than pure feldspar?

Mr. Watts: It deforms very much more quickly after it begins to deform; therefore I assume you would say it is softer. In commerce, you never make a mixture of 90 percent feldspar plus 10 percent of quartz. In ordinary porcelain bodies, you would have about 18 percent of feldspar and perhaps 40 percent or 35 percent of quartz; so that you would have 70 percent of quartz as against your 30 percent of feldspar in ordinary porcelain mixtures. This is simply a research covering the feldspar-quartz mixtures which we find in nature, not with any attempt to duplicate the feldspar-quartz mixtures we find in pottery bodies. The province in which I am working would hardly permit me to undertake the investigation of feldspar and quartz mixtures in the proportions in which they occur in pottery bodies.

Mr. Doe: I came in a little late and didn't hear the first part of the paper. How do you prepare those samples?

Mr. Watts: In this case I use the graphic granite.

Mr. Doe: I mean the mechanical preparation?

Mr. Watts: I simply pulverized them all to pass a 200-mesh sieve dry, and these powders were then worked up with a small amount of dextrine, enough to hold them together, and made into cones.

Mr. Doe: Well, this perhaps may be an academic point, but where fineness is such a factor in fusion and the difference between your modes of heating is not very great, what would be the effect if you were very careful in separating the particles to a uniform size?

Mr. Watts: With regard to that, I would say that these were all very carefully ground in order to get them as near as possible of the same sized grains; that is, they were ground to pass a 200-mesh sieve and sieved very often in order that the material should be as nearly 200-mesh material and as little of it finer than 200-mesh as we could get.

Mr. Doe: How could you prevent that fineness?

Mr. Watts: Of course you will always get a certain amount of material that is finer than 200-mesh. It you take 200-mesh material and continue to grind it you will get it all down to a 1000 or a 2000 mesh; whereas, if you simply crush it and it is put upon the screen and you continue that, you will find, by the use of the microscope, that you will have a very small proportion of exceedingly fine material. I don't believe it is possible to grind that material so that it is all going to be between 200 and 220 mesh, but there were only the two alternatives; one was to pulverize the material down until it was infinitely fine, or else keep it about the same ratio of coarse to fine, and that we attempted to do.

Mr. Walker: Well, you had a straight alternate, that is, to make a fusion and then grind that fusion; have you done that?

Mr. Watts: I did that last year and found no difference in the deformation effect. I did not want that data. What I wanted was the deformation effect of the feldspar as it comes to you or any other man who proposed to use it. It is out of the question to melt the feldspar once in order to get a low deformation point; the cost of the operation would be too great, and while it might be justified

in a few instances, in the majority of instances it would be out of the question for a potter to melt his feldspar and then pulverize it again, so I considered that this was more useful than in the other way.

Mr. Purdy: I understand you challenge the statement that pegmatite is not a eutectic?

Mr. Watts: No, I don't challenge any statement. I simply say that so far as we have been able to determine the graphic granite is not the deformation eutectic. It may be the melting point eutectic. That, I am not discussing.

Mr. Purdy: The view of physicists would give us the eutectic between feldspar and quartz as 75 to 25, but that would not be the eutectic that Mr. Watts is talking about.

Mr. Watts: These are deformation eutectics, not melting point eutectics.

Mr. Spier: To obtain uniform particles, I would suggest that after pulverizing your material you pass it through a 190-mesh sieve. The material which passes through that sieve should then be passed through a 200-mesh sieve, and the product which remains on the 200-mesh sieve, known as the residue, you will find to be more uniform than if you were to take the entire product which goes through a 200-mesh sieve, as you can readily understand. By pursuing the first course, the residue on the 200-mesh sieve will be almost uniform in fineness, as it represents material which has all passed through 190-mesh sieve yet is too coarse to pass through a 200-mesh sieve, whereas if you simply use a 200-mesh sieve in your screening process, the product which passes through the sieve will contain material of various degrees of fineness. If on the other hand you use the product which remains on the 200-mesh sieve, or residue, it also would not be uniform, containing coarse particles which should have been eliminated by a preliminary screening.

Mr. Watts: Of course that is true, but wherever you are pulverizing two materials, one more brittle than the other and of different crystalline structure, your grinding process is going to act more abruptly upon one than the other. Therefore, where you are dealing with a mixture of quartz and feldspar, the minute you begin to sieve out any proportion of that, you destroy the whole object of your investigation, that is you lose a greater percent of your felds-

par than your quartz, or vice versa. The result is, you would not dare to resort to a method of that sort in this kind of investigation. You must use every bit of your material.

Mr. Spier: In that connection, would there be any objection to your pulverizing and screening each product separately, then making your mixture so as to be absolutely positive of the fineness and quantity of each commodity contained in the material which you propose to proceed to experiment with.

Mr. Watts: What I am trying to do is to determine how much there is in this mixture. I don't know how much there is in it. If I knew, I wouldn't be carrying on this investigation.

Mr. Montgomery: Couldn't you arrive at a conclusion by analyzing carefully separated feldspar and analyzing also the pegmatite as it is?

Mr. Watts: Yes, I want to do that. In fact those were the analyses I expected to have to present this morning; but owing to some delay, the analyses are not here. What I want to show is whether or not this simple process of pulverizing a little of the feldspar, and pulverizing some of the graphic pegmatites, won't give us the same results which we can obtain by chemical analysis. If that is the case, then any ordinary potter can make such tests without resorting to the chemical analysis, which most of our ceramic men hate to resort to and which they do not resort to unless they are absolutely forced to it. If we can determine the ratio of quartz to feldspar by comparison of the deformation temperature of the graphic granite and the deformation temperature of the feldspar alone, without resorting to analytical chemistry, it will be a very convenient addition to our ceramic knowledge.

Mr. Mayer: There is a commercial side to this thing and a practical side, that I want to speak about. There are very few of our flint spar grinders in the United States who knew what the word eutectic meant till they came to some of our meetings; then they got a fool idea in their heads that the more flint they put in this spar, the softer they were going to make it (Laughter). That's a fact. Mr. Walker can bear that statement out. They came here and the question was up; about a meeting ago we were fortunate enough or unfortunate enough to have some spar grinders. They'd say "Don't you understand that it's no good using pure spar? We've

got to put a little flint in it to make it softer." You get a carload of material in and the spars that ought to go down along cone 7 or 8, won't move hardly at cone 9 now. You know in this Maine feldspar there's a great deal of flint has to be taken out in the cleaning of it, which they used to take out. Now they are leaving the bulk of it in, with the idea that they are making it soft. If you talk to those men, they will try to explain to you, as they try to explain to me, that they are simply working on the lines laid down by the American Ceramic Society, that they've got to put some flint in. I wish some of you fellows would explain to them where they stand about this matter, because it would be a great help to us manufacturers if you would do it.

Mr. Watts: I spent a good portion of last summer in the Maine feldspar fields, and they tell me there that they did not want to put the quartz in, but the manufacturer insists on having it in; so that's the other side of the proposition.

Mr. Mayer: I don't think that is a correct story, because a potter would not tell a feldspar man to put flint in—why would he pay for flint as feldspar when he can get the flint at half the price of feldspar?

Mr. Watts: In the majority of the Maine feldspar deposits the quartz content runs from five to forty percent. In years gone by they were very particular and they used nothing but the pure feldspar; they rejected all the quartz, but you know you can't keep on eating good apples everlastingly; you've got to get to the poor ones after a while. Now, in the deposits which are open, you have used up the best part of the feldspar, the part which would have enabled you to have perhaps 5 percent or 10 percent of quartz. Now in order to meet the price, which the operator tells me the potter insists on maintaining where it was five or six years ago, they cannot afford to mine deeper or pump more water or open new deposits; but they are fighting to maintain this ratio as nearly the same as possible. They tell me that they take this graphic granite and they sweeten it with just as much feldspar as they can possibly get, just as much pure feldspar, and that they are shipping and have continued to ship for a number of years, a feldspar-quartz mixture of about 15 percent of quartz. It seems pretty difficult for a man to believe that it never goes above 15 percent, because of the fact that

there is no system except an optical study of the material to guide them in maintaining this uniform ratio. They tell me however, that the uniform mixture is about 85 percent of feldspar and 15 percent of quartz.

Any statements that we make regarding eutectics must I realize be very carefully printed and very carefully used, because of the fact that it is a very simple proposition for a feldspar manufacturer to say, if 5 percent of quartz is good, 10 percent is better, and if 10 percent is better, 20 percent is quite an improvement and 40 percent ought to be splendid; but that is a thing I have been trying to explain and shall continue to try to explain to the feldspar manufacturers. I think they, as a rule realize the importance of producing a feldspar which is absolutely pure and would like to do so if they could. I believe, however, that it is practically out of the question, without the finding of enormous lenses of pure feldspar, of which there are not a great many, to be able to produce, from the feldspar of the Maine district, a continuous supply of high grade, pure feldspar. I think we will always have to submit to a small quartz content; but, as I said in opening this paper, the value of the Maine feldspars is their exceeding whiteness and very fine quality and practical freedom from iron, and in order to get that, I believe we will always have to tolerate a comparatively small content of quartz. The problem is to keep that quartz content just as low as we possibly can.

Mr. Hope: Did I understand you to say that graphic granite is used ground up with feldspar commercially?

Mr. Watts: That is practically 60 percent of the Maine feldspar of commerce.

Mr. Hope: Well, as a granite, it contains mica, does it?

Mr. Watts: No, as I stated in this paper, the graphic granites are remarkably free, from other impurities than quartz. Very much freer, so far as my observation has gone, than the ordinary pegmatites. Wherever you find a graphic granite, you find a pretty clean feldspar-quartz mixture. Very often you run into biotite and other materials, where you work in ordinary pegmatite, but where it runs into graphic structures, my experience has been that you find it pretty clean. That is merely a matter of experience with me; others might say differently.

A PROCESS OF MAKING SANITARY WARE

BY J. B. SHAW, PITTSBURGH, PA.

The object of this paper is to give to the readers of the *Transactions* a detailed description of a certain process used in the manufacture of sanitary ware. No attempt is made to compare the merits of this process with those of any other process.

GENERAL DESCRIPTION

The ware is made from a fire clay body by casting in plaster moulds. The body is allowed to dry thoroughly and a slip or engobe is applied by painting on with a brush. Over this is applied a raw, leadless glaze by painting on in the same manner as the slip is applied. The body, slip and glaze are all fired in a single fire in muffle kilns at cone 8 to 10.

The Body. The body used is composed of flint fire clay, plastic fire clay and grog. The fire clay is all mined in the vicinity of the plant. The flint clay is quite variable in character, at times carrying a very high percentage of free silica. The plastic fire clay is also quite variable, varying in color from a light gray to a black. The carbonaceous matter in this body is quite detrimental to the casting process. The soft clay also invariably carries a considerable amount of concretionary iron pyrites which will be mentioned again later. The grog is simply pieces of defective ware, which are thrown in the pan with the clay and ground. The body used consists of $1\frac{1}{2}$ parts by bulk soft clay, 1 part hard clay, 1 part grog. It is ground in a dry pan through a 10-mesh screen from which it drops into a bin over the blunger.

The Blunger. The blunger, built up of brick, is about 9 feet in diameter by 9 feet deep. The blunger arms are set horizontal and are made of iron bars 3 inches wide by $\frac{3}{4}$ inch thick. They set about 16 inches apart with a stationary arm intervening between each pair of rotating arms. No provision is made for varying the speed of the blunger, except by varying the speed of the engine; but this is a very important feature and in a plant properly equipped would be under control at speeds varying from 20 to 60 revolutions per minute.

Blunging. The blunging process is where the supposed secrets of the process begin to play their part. Before the clay is allowed to drop into the blunger, a barrel of solution is prepared as follows: to 400 pints of water, 20 pints sodium silicate solution (sp. gr. 50° Baumé) are added. This is put in a barrel and steam turned in the solution, heating it to a temperature such that the hand can just be borne in it without burning. The blunger is now started, and the body and solution run in together. The amount of solution required for a given amount of clay is determined entirely by the man operating the blunger, who knows from experience the proper consistency which the body must have for casting. The same man governs the speed of the blunger, this being so governed as to keep the body from heating during blunging, which is detrimental to proper working of the body in casting.

The operator mixes about as much body as he thinks is required for a day's casting, and allows the blunger to run, testing the body frequently, and adding more clay or solution as he thinks is required to give the proper consistency. After he has his body right, he allows the blunger to run for about an hour to insure thorough blunging. The body for a day's casting is usually made up the previous afternoon; and after standing over night the body must be blunged again for one-half to one hour. The success of the casting process depends entirely upon getting the body of the proper consistency before pouring, and it requires considerable skill on the part of the operator to accomplish this result.

Tests, made by weighing the $1\frac{1}{2} : 1 : 1$ body just as it came from the blunger, drying thoroughly and weighing again, showed this body to contain very close to 10 percent water when at the proper consistency for casting. The amount of water will vary very much with the amount of sodium silicate solution used and the percent of soft clay in the body.

It is quite generally known that the cracking of clay wares in drying is very greatly affected by the amount of water to be driven out. It will also be readily recognized that the addition of 10 percent of water to a body of the above proportions will leave it in a very stiff condition; but when 10 percent of a solution composed of 1 part sodium silicate solution to 20 parts water is added to this body, it makes it of the consistency of moderately thick

molasses. This mixture also has the virtue of absolutely refusing to stick to plaster moulds at any time.

This, then, is the nature of the body used in casting this ware. The body is carried in buckets and poured in the moulds, care being taken to continue pouring in a single mould until it is full. No description of the moulds will be given as they do not differ from those used in any other process. The length of time required between pouring and drawing the moulds varies according to the condition of the moulds, the thickness of the ware and consistency of the body when poured. Ware with a maximum thickness of 1 inch requires 5 to 6 hours when the body is poured of the proper consistency. Blocks were cast for kiln construction which were about 8 in. by 10 in. by 12 in. These required about 20 hours for drawing.

Finishing. After drawing the moulds, the ware is finished by going over it with a spatula, and trimming off and smoothing over rough places left at joints in the moulds. It is then placed on the drying floor, which is a brick floor heated by direct fire from flues running under it. The ware is set level in clay dust directly on the floor. The time required to dry a piece of ware 1 inch thick and longest side about 18 inches by 20 inches is about four days.

Preparing for the Slip. After the body is dry, it is taken from the drying floor and set up on benches preparatory to painting on the slip. As the ware is taken from the drying floor, it is all carefully inspected for cracks, warpage and other defects, and nothing but perfect ware set up to paint, for any defect in the ware at this stage will only be exaggerated by future operations. Sometimes, the ware to be painted is gone over with a damp cloth to destroy the hard skin on the surface and leave a rough surface to which the slip will adhere better.

The Slip. The slip to be used is made up in large quantities by blunging and kept in bins or tanks built up with enameled brick. The consistency of the slip as kept in stock is heavier than will be required as used.

The preparation of the slip for painting is the most variable and hardest to control of any operation in the entire process. The three most potent factors in determining the procedure in preparing the slip are:

1. The composition of the slip.
2. The temperature of the slip room.
3. The temperature of the painting room.

In general, the following procedure will be found to give satisfactory results, the exact procedure being determined by study of the conditions as given.

Make up the slip to weigh 24.5 to 29 ounces per pint. Now measure out 66 pints of the slip and place in a receptacle of convenient size to stir, a wash tub or half barrel being about right. A good quality of gelatin is added to the slip as follows: For each pint of slip, weigh out 0.45 to 0.80 ounce of gelatin, add just sufficient water to cover when pressed down and allow to stand for a few minutes until the gelatin has absorbed the water and become soft; now heat this mixture in hot water or otherwise, being careful not to get too hot, until the liquid is thin and all lumps have disappeared. Pour the hot gelatin in the slip as prepared above and stir very rapidly while pouring in the "glue" or "gelatin," and continue to stir vigorously until the mixture is of uniform consistency. Upon first pouring in the glue, the mixture will become very heavy and hard to stir but it will soften upon further stirring, and will soon be thin enough to run through a screen. Immediately after stirring, screen through a fine screen (at least 80-mesh) into a cold receptacle. After screening allow to stand for a few hours in a cold room. When properly mixed, upon standing the mixture will become very thick and paste like, the best results having been obtained when it assumes the consistency of liver.

The room in which the slip is prepared should be kept cold at all times. The room in which the ware is painted should be cool and clean. With any slip, the warmer the room in which it is prepared, the higher the percentage of glue required to make it up for painting. The higher the clay in the slip, the higher the glue content required. Ball clay is especially hard to handle in this process and should be kept as low as possible. Sometimes the slip makes up to a good, livery condition; but when you try to paint it on the ware it drags on the brush and can not be applied in a thin uniform coat, which almost invariably results in the slip cracking and peeling from the body before going to the kiln.

The slip must be of the proper consistency for painting and must work easy under the brush, giving the workman time to spread it over the surface of the body in a thin, uniform coat. In order to get this result the following rules must be observed:

1. Keep the slip room cold.
2. Keep ball clay in slip very low.
3. Keep total clay in slip as low as possible.
4. Add gelatin when thin and hot.
5. Stir very rapidly and long enough to get uniform consistency.
6. Screen immediately after stirring into a cold receptacle to cool rapidly.
7. High ball clay requires high glue and light weight of slip.
8. High total clay requires high glue and light weight of slip.
9. Warm work room requires high glue content and heavy weight of slip.
10. Do not use slip until 5 hours old nor after it becomes so old as to develop very offensive smell, usually 5 or 6 days old.

Painting. Having made the slip of proper consistency for painting, a small amount, about a quart, is put in a paint bucket and, together with an ordinary paint brush of convenient shape and size, is given to the painter. This slip is painted over the surface of the ware, care being taken to spread the slip well and apply a thin uniform coat. The ware must be thoroughly dry before painting and, in general, one day should elapse between the application of the subsequent coats. The number of coats of slip required for the ware depends upon the consistency of the paint and the nature of the slip. The object of the slip is to hide the body under it, making the ware when finished look like white ware. At the same time the slip must be practically non-absorbent, in order to stand the ink test to which this class of ware is subjected. With a given slip, the more thoroughly it is vitrified, the thicker it must be to hide the body. In general, five to seven coats of

slip are painted on the ware, giving a total thickness when burned of $\frac{1}{20}$ to $\frac{1}{10}$ of an inch.

During the painting of the ware, the painter should watch for cracks, crazes or peeling of the slip; and when a piece develops any of these defects, it should be taken to the scrap pile, because it is time wasted to try to patch it or paint over any defects.

After the last coat of slip is applied, the surface of the ware is quite rough from brush marks and hard from the effects of the glue. It is now sand-papered until smooth, care being taken to take as little of the slip off as possible. In order to be able to tell how much slip is taken off in sand-papering and also to tell how each coat of slip is going on in painting, each batch of paint is colored with aniline dye when made up and when painting, each coat is of a different color from the preceding one.

After the ware is sand-papered smooth and brushed clean, the glaze is applied. The glaze is made up in exactly the same way and applied in the same manner as the slip. The glaze, being low in clay, always requires less glue and works better than slip. Generally two or three coats of glaze are applied.

It is not considered worth while to go into detail in describing the setting and burning. The ware is set in muffle kilns, and burned at cone 8 to 10. The kilns in use are not a good type and the temperature may vary two or even three cones with the most careful firing, which is very high for muffle kilns.

SOME DEFECTS AND THEIR CAUSES

Some of the common defects encountered in using this process will now be given.

Probably the most common and worst trouble in this process is clay cracks. Cracks may be found in the ware immediately after drawing the moulds. They may be caused by:

1. Rupturing the ware by awkwardness in drawing the moulds.
2. Not having the moulds properly fitted and fastened together.
3. Leaving the ware in the moulds too long before drawing.

4. Drawing the moulds too soon.
5. Not having the body of the proper consistency when pouring.
6. Too high soft clay content in the body.
7. Body too short.

When cracks occur in this stage, if they are small and not numerous, they may be patched by firmly forcing a course, short body into the crack. If, however, the cracks are large or numerous, it will be money saved to haul the ware to the scrap heap.

Having placed the ware on the drying floor in perfect order, cracks may develop, the cause of which may be:

1. Too rapid drying.
2. Unequal thickness of adjacent parts of the ware.
3. Unequal speed of drying of adjacent parts of ware.
4. Too high soft clay content in the body.
5. Body too short.

When cracks develop at this stage, the only course is to haul the ware to the scrap pile.

Another common defect is the warping of the ware during drying. This may be caused by:

1. Ware not setting level.
2. Unequal speed of drying of adjacent parts.

This defect is obviously incurable.

Slip Troubles. In painting the slip on the ware, if it works easy under the brush and goes on in a nice even coat, no trouble is likely to result, unless a coat is applied over a body or previous coat which is not thoroughly dry, in which case the slip is likely to peel off in flakes when applying some subsequent coat. If the slip works hard under the brush, it will go on heavy and will crack and peel off in large flakes. If the slip does not contain enough glue to harden when dry so as to be scratched with difficulty with the finger nail, it is likely to brush off leaving thick and thin places or to peel off. If slip cracks or peeling develops in any piece of ware before or after the painting is finished send the ware to the scrap heap.

The glaze will seldom give trouble in this stage. Be sure to get enough on to prevent dry spots, but do not get it so heavy as to run down vertical sides and cause heavy and crazed corners.

Defects in Burned Ware. After burning, the ware may exhibit the following defects:

Clay cracks, caused by,

1. Opening of cracks which were in the raw body but not found.
2. High silica content of flint fire clay.
3. Too high soft clay content of body.
4. Swelling of concretionary iron.

Slip cracks, caused by,

1. Slip following body in cracking.
2. Cracks caused in painting, but not found before setting the ware.
3. Iron concretions swelling and bursting out through the slip.

Slip peeling from body, caused by,

1. Steaming the kiln.
2. Poor fit of slip to the body.
3. Peeling caused in painting but not found.

Slip crazing, caused by,

1. Poor fit on the body.
2. Slip too heavy.
3. Chilling slip in cooling.

Bare spots, caused by,

1. Sand papering slip off after properly applied.
2. Too low glue content in slip, causing uneven coat in painting.

Warped ware, caused by,

1. Warping in drying but not found by inspector.
2. Ware set in kiln improperly.
3. Shape of the ware causing unequal strains in shrinking.
4. Viscous vitrification of the body. This being probably exaggerated by the action of sodium silicate.

In giving these defects and their causes, the writer does not claim to have given all the causes for any single defect, the intention being to give those defects and their causes which have been actually observed. It is believed, however, that these defects and their causes as given cover fairly well the troubles incidental to making this class of ware with this particular process.

EXPERIMENTS

In an attempt to find a slip which could be handled properly by the above process, and work well as a slip for sanitary ware, a series of slips was made up by one of the owners of the plant and the writer was instructed to run them through the process in the regular commercial way. As the series as made up only covered a small field, the writer made an additional series in order to have the entire series when completed cover fairly well the field in which satisfactory slips are likely to be found.

A glance at this work will reveal the fact that very little indeed was learned about these slips. The writer has interpreted the results to the best of his ability from the data obtained and will have to admit it was a great surprise to find the regularity they showed when plotted on the tri-axial diagram.

Materials Used. The materials used for these slips were: Cornwall stone, potash feldspar, French flint, whiting and English china clay. It will be noted that none of these slips contain ball clay. The reason for this is the fact that previous experience had shown that ball clay in the slip made it very difficult to get the slip right for painting; and when painted on the ware, the slips containing ball clay always gave trouble from cracking and peeling. Consequently, in making up this series, it was the aim to get the proper vitrification from feldspar, stone and whiting and allow the glue to replace the ball clay in bonding the slip together while in the raw state.

The Slips. The first series is given in the form in which it was handed to the writer in Table 1. The series formulated by the writer is shown in Table 2. It is highly probable that the action of the glaze would influence the slip, but this has not been considered in this case. Twenty pounds of each of the slips was

TABLE 1

NO.	CHINA CLAY	STONE	FLINT	SPAR	WHITING
1	30	40	20	0	0
2	36	0	0	54	10
3	38	0	0	52	10
4	42	0	0	48	10
5	44	0	0	46	10
6	40	50	10	0	0
7	30	50	20	0	0
8	25	50	25	0	0
9	20	50	30	0	0
10	40	0	20	30	10
11	40	35	20	0	5
12	40	0	10	40	10
13	30	0	20	40	10
14	30	40	25	0	5
15	30	40	30	0	0
16	25	40	25	0	10
17	35	0	10	45	10
18	25	0	20	45	10
19	30	0	10	50	10
20	20	0	20	50	10
21	30	60	0	0	10
22	20	60	10	0	10
23	30	60	5	0	5
24	20	60	15	0	5
25	30	55	10	0	5
26	30	50	15	0	5
27	25	50	20	0	5
28	40	45	15	0	0
29	30	45	25	0	0
30	25	45	30	0	0
31	20	55	20	0	5

carefully weighed and mixed thoroughly with sufficient water to make the slip weigh 27.5 ounces per pint. To this was added 0.45 ounce per pint of glue. The temperature of the slip room was about 50°; and with these conditions, all slips containing 40 percent or less of clay made up to a good consistency and worked fairly well under the brush, the result obtained being directly proportional to the content of clay.

TABLE 2

DESIGNATION	SPAR	FLINT	CHINA CLAY	LIME
A	15	20	65	1
B	15	30	55	1
C	15	40	45	1
D	15	50	35	1
E	20	20	60	1
F	20	30	50	1
G	20	40	40	1
H	20	50	30	1
I	25	20	55	1
J	25	30	45	1
K	25	40	35	1
L	25	50	25	1
M	30	20	50	1
N	30	30	40	1
O	30	40	30	1
P	30	50	20	1
Q	10	45	40	5
R	10	40	40	10
S	10	35	40	15
T	20	30	40	10
U	25	25	40	10
V	30	20	40	10

In the second series,

A could not be painted at all.
B went on in thick and thin patches.
C was painted on with difficulty and peeled off later.
D worked fairly well.

The same results were noted throughout both series.

Consequently, all slips were made again, making up to weigh 26 ounces per pint and 0.5 ounce per pint of glue was added. With these conditions, all slips made up in good shape and worked fairly satisfactory with the exception of A, in the second series, which finally cracked and peeled off the body after painting on the third coat.

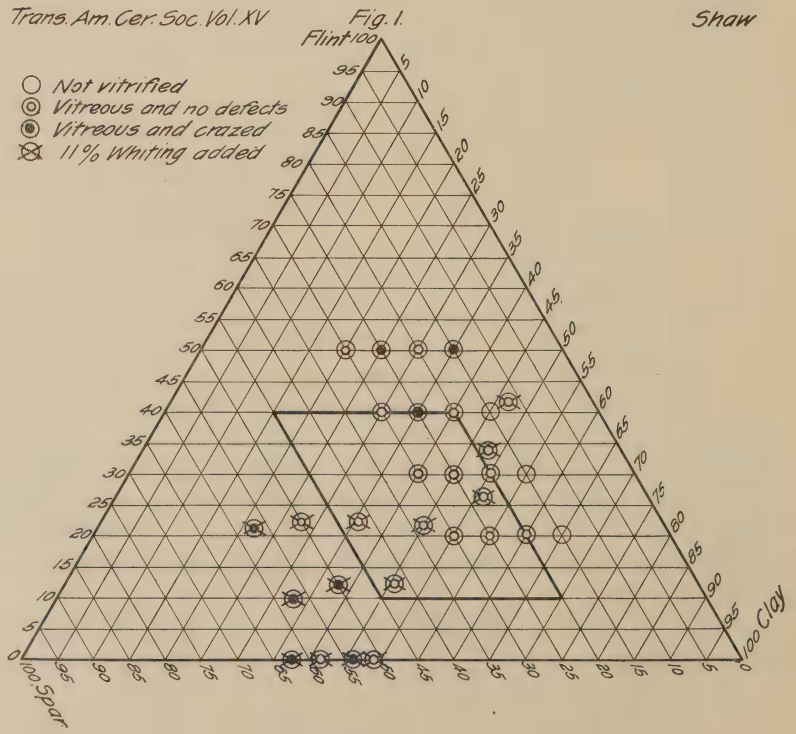
Five large pieces of ware coated with each of these slips, each piece having six coats of slip. The same glaze was used on all bodies and was as follows:

Stone	24.00
Feldspar	41.25
Flint	15.00
Whiting	14.00
Zinc oxide	8.25
China clay	2.50

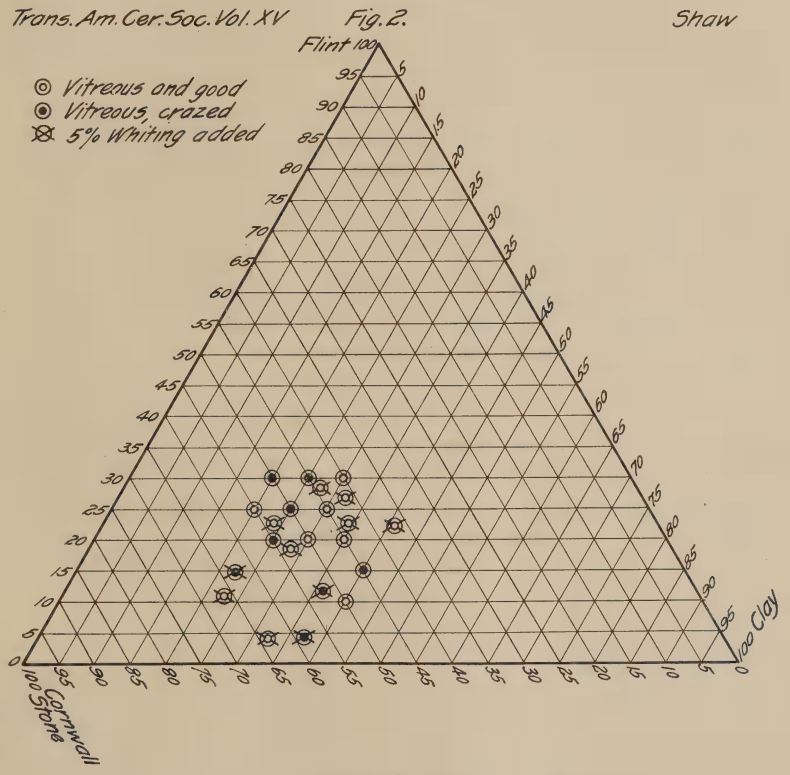
This glaze works well at 27.5 ounces per pint with 0.35 ounce per pint of glue added. It is very likely to craze on most bodies and requires about cone 9 to mature properly.

All of the slips were burned to cone 9 half down. Having drawn the ware from the kiln and set it up in order as it occurs in the series, the method of testing was to compare their color and then, with a hammer, test the hardness of the slip.

Results. The results obtained are shown in Tables 3 and 4. In giving the results, crazing refers to the slip, no attention being paid the glaze. These results plotted on the tri-axial diagrams



are shown in Figures 1 and 2. In plotting the results, the compositions were recalculated, making the three principal ingredients equal 100 and allowing the lime as a straight addition. Practically no information is obtainable from the diagram of the stone slips. A comparison of the two diagrams demonstrates pretty thoroughly that the existing prejudice against feldspar in favor of Cornwall stone for slip production is ungrounded.



CONCLUSIONS

A study of the diagrams of the feldspar slips leads to the following conclusions:

1. A clay content of more than 40 percent requires a feldspar content of more than 15 percent to get sufficient vitrification at cone 9, unless more than 1 percent lime is present.

TABLE 3

NO.	RESULT	NO.	RESULT
1	Very vitreous, no crazing, looks good	17	Very vitreous, crazed slightly
2	Very vitreous, crazed in long lines	18	Very vitreous, quite thin, not crazed
3	More vitreous, not crazed	19	Very vitreous, dark color, crazed badly
4	Not so vitreous, crazed	20	Very thin, badly crazed
5	Very vitreous, not crazed	21	Very vitreous, not crazed
6	Very vitreous, not crazed	22	Very thin, very vitreous, not crazed
7	Very vitreous, not crazed	23	Very nice, hard and white
8	Very vitreous, crazed fine lines	24	Quite vitreous very white, crazed badly
9	Very vitreous, crazed fine lines	25	Nice color, very vitreous, but crazed
10	Quite vitreous, not crazed	26	Very vitreous, thin, not crazed
11	Less vitreous, not crazed	27	More vitreous, thin, looks good
12	Less vitreous, not crazed	28	Very vitreous, slightly crazed
13	About the same as 12	29	Very vitreous, badly crazed
14	About the same as 12	30	Very vitreous, badly crazed
15	About the same as 12	31	Very vitreous, badly crazed
16	About the same as 12		

2. An addition of 10 percent lime can be made without introducing any material difficulties in slips containing more than 40 percent clay. More than 10 percent lime is likely to make the slip too vitreous, attacking the glaze or destroying opacity.

3. Slips with less than 40 percent clay and 15 percent or more spar are likely to be too vitreous and to craze.

4. Slips with more than 45 percent spar are too vitreous and liable to craze.

5. Although a small percentage of lime is undoubtedly helpful in starting vitrification, it is not essential for the production of good slips. The best slips in this entire series were feldspar slips and were in the field outlined above. The limits given for this field seem very wide; but a glance at the chart shows that no defects were noted in any of the slips within this field, and hence no closer limitation can be set from this study.

6. Satisfactory slips are very likely to occur anywhere within the following limits:

Feldspar.....20 to 45 percent
Flint.....10 to 40 percent
China clay.....30 to 60 percent
Calcium carbonate..... 0 to 10 percent

TABLE 4

MARK	RESULT	MARK	RESULT
A	Not in kiln	M	Very vitreous, not crazed, looks good
B	Very white, chalky, not crazed	N	Thin, vitreous, not crazed, looks good
C	Very white, chalky, not crazed	O	Thin, vitreous, not crazed, looks good
D	Very white, quite vitreous, crazed badly	P	Very thin, vitreous, not crazed, looks good
E	Very white, quite vitreous, not crazed	Q	Very thin, vitreous, not crazed, looks good
F	Very white, quite vitreous, not crazed	R	Very thin, very vitreous, not crazed, looks good
G	Very white, somewhat chalky not crazed	S	Glaze has attacked badly, too vitreous, bad color
H	Very thin, vitreous, not crazed	T	Very vitreous, not crazed, looks good
I	Quite vitreous, not crazed	U	Very vitreous, not crazed, looks good
J	Very vitreous, not crazed, looks good	V	Very vitreous, not crazed, looks good
K	Quite vitreous, crazed quite badly		
L	Thin, very vitreous, crazed badly		

THE PHYSICAL CHEMISTRY OF SEGER CONES

BY ROBERT B. SOSMAN, GEOPHYSICAL LABORATORY OF THE CARNEGIE INSTITUTION

No doubt every member of this Society has used Seger cones for the measurement of heat effect. Furthermore, a number of excellent papers on this subject have been given before this Society in past years and these have been quite actively discussed. There is, therefore, little need for my going into the facts regard-

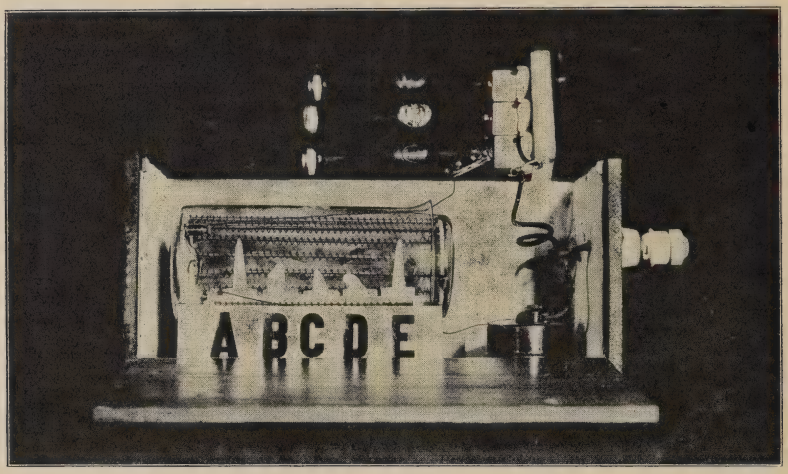


Fig. 1. Lecture experiment showing control exercised by the eutectic melting point upon the indications of pyrometric cones.

ing pyrometric cones; but there are certain familiar properties of Seger cones which seem not to have been clearly explained on the basis of physico-chemical laws. It seemed that a brief treatment of these from the standpoint of the laboratory worker in silicates might be of interest.

I can best introduce the subject by a simple lecture experiment. I have here five cones, made up of mixtures of sodium and potassium nitrates. Cone A is 100 percent sodium nitrate; cone B contains 25 molecular percent potassium nitrate; cone C contains

50 percent, and cone D 75 percent potassium nitrate and E is pure potassium nitrate.

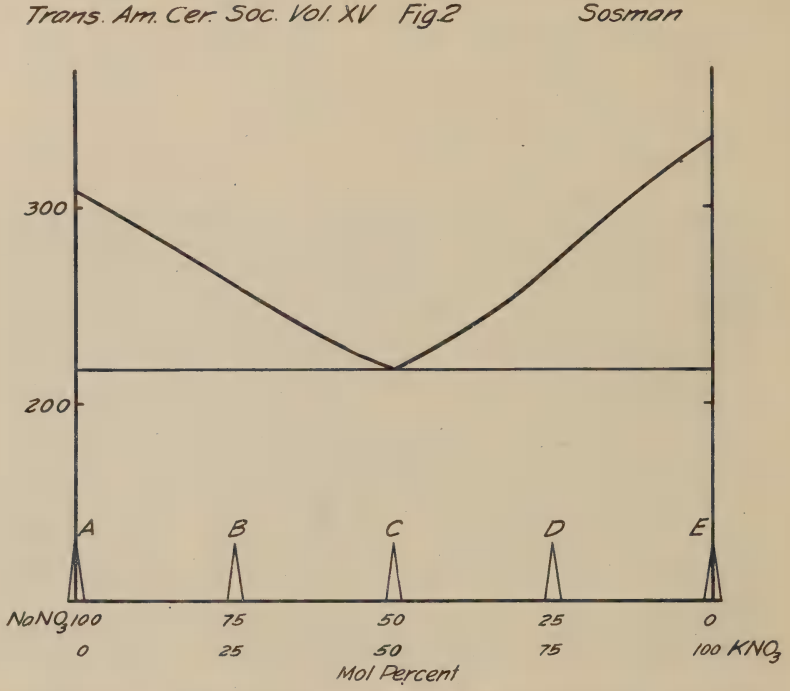
On the basis of proportionality between fusing temperature and composition, we should expect cone A to go down at the melting point of sodium nitrate, namely 308°, followed by B, C, and D in order, and ending with cone E at the melting point of potassium nitrate, which is 337°. As a matter of fact cone C starts first. But what I want you to note especially is that B and D are coming down at the same time.[1]

In Figure 2 are plotted the compositions and melting temperatures of the cones used in the experiment. Potassium nitrate above 337° is of course a liquid; as it is cooled down it solidifies at that temperature all at once. If we add a little sodium nitrate to it, it will begin to freeze at a lower temperature, just as water begins to freeze at a lower temperature when salt is dissolved in it. The continued addition of sodium nitrate to potassium nitrate continues the lowering of the freezing point, down to a point where further additions will cause the mixture to begin freezing at a *higher* temperature. A familiar analogy is the case of salt and ice. If we add salt to ice in increasing amounts, we get down to a certain minimum temperature, and further additions will give a higher temperature. This composition of minimum freezing point is known as the eutectic composition. In the case of these two nitrates it happens to be very nearly 50 molecular percent. In general, it might lie anywhere between the two pure substances. I have gone into some detail in this explanation, because I believe these facts are so fundamental that they cannot be repeated too often.

Any mixture except the eutectic will contain, as you can readily see, a certain proportion of this eutectic mixture, together with an excess of one of the components. For instance, the mixture of 25 percent of component A and 75 percent of component B will contain 50 percent of the eutectic mixture and 50 percent of excess of B. Therefore, when the temperature reaches the eutectic melt-

[1] See Figure 1. The furnace used for this experiment consists of a cylindrical steel cage, open in front, made of two metal rings into which rods are screwed. Glass tubes are slipped over the rods, and a helix of about 40 feet of No. 20 nichrome resistance wire is threaded over the glass tubes. The cones are cast in an iron mold, and stand on a shelf of asbestos board. The furnace is inclosed by two glass beakers, one slipping inside of the other.

ing temperature, 50 percent of the mixture will melt. Any cone made up of a mixture of these two components will consist, above the eutectic temperature, of a mixture of solid and liquid, the liquid being fairly thin; hence all the cones between A and E will



Fusion curve of the system $NaNO_3$—KNO_3. Recalculated to molecular percentages from data of Carveth.[2]

come down at once, because a thin liquid, even though it contains a solid in suspension, cannot stand up in the form of a cone.

That is the fundamental principle which I want to bring out. We will apply it first to the series of cones numbered 28 to 42. Here we have a series whose relations are easy to represent, because

[2] J. Physic. Chem. II, 209-228, (1898). Later investigation by Hissink, in Z. physik. Chem. XXXII, 537-563, (1900), shows that this is not a simple eutectic system as stated by Carveth, but that each of the component salts carries the other in solid solution to a limited extent. This fact does not change the form of the fusion curve, however.

it contains only two components, silica and alumina. This series has been investigated by Shepherd and Rankin at the Geophysical Laboratory.[3]

Quartz is the form of silica used in making up cones 28 to 42. At temperatures above 1600° quartz changes rapidly into cristobalite, which melts at about 1625°.[4] Its rate of melting at this temperature is, however, very slow.

Alumina enters the cones in the form of kaolinite, $Al_2O_3.2SiO_2.2H_2O$ and, in the higher numbers, pure aluminum hydroxide. Kaolinite is not a stable compound at high temperatures, even after loss of water, and appears to decompose into aluminum silicate (Al_2SiO_5) and free silica. The only compound that occurs on the fusion curve is sillimanite, Al_2SiO_5. This compound melts at 1816°. Pure alumina melts at 2050°.[5]

None of these three substances, cristobalite, sillimanite, and alumina, contains the others in solid solution to any considerable extent. A eutectic mixture forms between cristobalite and sillimanite, and another between sillimanite and alumina. We have here, then, two simple binary systems side by side; each may be expected to behave just as the series of little nitrate cones is behaving.

The curve of Shepherd and Rankin is shown in Figure 3. On the same diagram are shown the compositions of cones 28 to 42, as well as the nominal and the experimentally determined temperatures at which the cones fall.

On the basis of what we have seen happening in the case of the nitrate cones, we should expect that the cones which represent pure compounds should stand up indefinitely at temperatures below their melting points. All the others should come down at or near the temperature of the eutectic, excepting those which lie so close to the pure compound that the excess component forms a rigid skeleton which is not pulled down by the flowing eutectic. Thus numbers 28 to 36 should come down near 1600°, 38 and probably 37 above 1800°, 39 to 41 at about 1800°, and 42 at 2050°.

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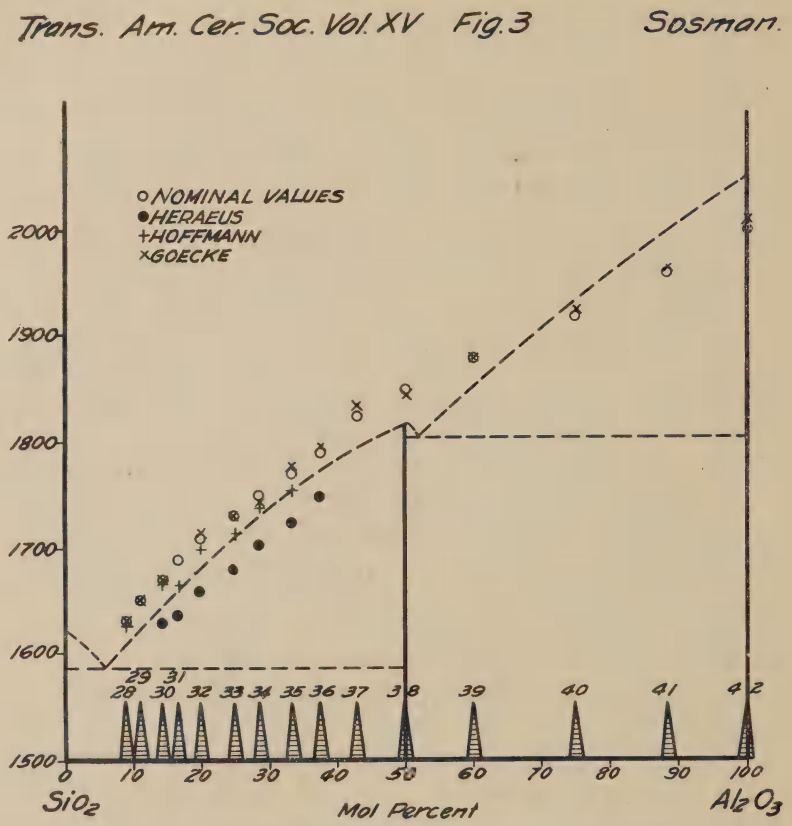
[3] *Am. J. Sci.* 28, 293–333. 1909.
[4] C. N. Fenner. *Am. J. Sci.* 1913.
[5] Kanolt. *J. Wash. Acad. Sci.* 3, 315–318. 1913.



Composition-temperature diagram for the system $SiO_2-Al_2O_3$, according to Shepherd and Rankin,[6] showing the composition of cones 28—42.

The published determinations[7] of the indicating temperatures of these cones show that they fall near, and at most not far below, the curve of Shepherd and Rankin. These determinations were all made in laboratory furnaces, at fairly rapid rates of heating.

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[6] Am. J. Sci. XXVII, 302, (1909.)

[7] Heraeus and Haagn. *Zs. angew. Chem.* 18, 49–53. 1905. Hoffman and Meissner. *Tonind. Ztg.* 33, 1577–1581. 1909. *Zs. Instr.* 30, 179–189. 1910. Goecke. *Metallurgie.* 8, 667–676. 1911. These experiments have been corrected to the uniform scale on which the palladium melting point is 1549°, and platinum 1755°.

But Kanolt reports that, at slower rates, the temperatures indicated by these cones fall 40° to 70° below the nominal.[8]

I have made a simple test of the effect of slow heating upon a number of high temperature cones which Dr. Kanolt had on hand at the Bureau of Standards. Number 28 (Orton and Berlin), 29 (Orton), 30 (Orton and Berlin), 31 (Orton) and 33 and 34 (Berlin) were all heated together in a covered crucible in a Fletcher gas furnace. The temperature, measured with a platinum-platinrhodium thermoelement, rose for one hour and then was held as steady as possible for five hours. The average temperature during this time was 1616°, which is below the nominal temperature for No. 28. At the end of five hours all the cones were down except 33 and 34; 33 was about one-fourth down, and 34 had started to bend. Microscopic examination of No. 34[9] showed that it consisted, after cooling, of a felted network of sillimanite crystals, with about an equal quantity of isotropic material of refractive index between 1.47 and 1.495. The index of this latter material apparently lies between that of pure fused silica and that of cristobalite, and it is perhaps a submicroscopic mixture of these.

We have seen, therefore, that if given sufficient time, these cones tend to reproduce the behavior of our experimental nitrate cones. What then are the causes for the delay in their response to the temperature?

The first and most important cause is the fact that the silicate cones are not homogeneous, in the chemical sense. Cones 28 to 41 are made up of mixtures of quartz and kaolin, or kaolin and alumina. The quartz must invert into cristobalite, and the kaolin must decompose into cristobalite and sillimanite. In cones 28 to 37, sillimanite and excess cristobalite must then melt together into the eutectic; in cones 38 to 41, cristobalite and excess alumina must unite to form more sillimanite, and this again melts down with excess alumina into a eutectic. The cones as made up have therefore not the same physical constitution that they would have if first melted and then made up out of the melted material.

The first cause of delay, therefore, is the chemical reaction taking place between these solids to bring them into their final con-

[8] Burgess. "Measurement of High Temperatures," p. 376. 1912.

[9] Microscopic examinations by Dr. H. E. Merwin.

dition of equilibrium. They do combine, however, in the solid state, and there is considerably more diffusion and reaction in the solid state than is ordinarily supposed. This is well shown by a simple lecture experiment. (Two coarsely crystalline organic solids, guaiacol and salol, were mixed in a test tube, and immediately began to liquefy; in a few minutes they formed a clear liquid.)[10]

Guaiacol melts at 28° and salol at 42°. Both of these solids will therefore remain crystalline indefinitely at the ordinary temperature of the room, about 20°. But their eutectic mixture melts considerably below room temperature. If the solids are mixed, therefore, they are not in equilibrium, and the liquid eutectic immediately begins to form at every point of contact between the solid crystals.

In the same way cristobalite and sillimanite should liquefy one another, even though the temperature is below the melting points of both components, provided only that the temperature is above the melting point of the eutectic. But the fact that this interaction must first take place constitutes, as I have said before, the first reason for delay in the response of the cone to the high temperature.

The second cause for delay in cones is the very slow time-rate of melting of silica and the alkali feldspars. Silica and the highly silicic feldspars are peculiar in this respect, that they can be heated above their melting points and still remain crystalline.

This is not a stable condition, that is, not a "superheated" condition. We have always believed that crystals cannot be superheated, in the same sense in which a liquid can be undercooled, and this remains true, because during all the time while these substances are above their melting points, melting is going on. In the course of half an hour, at a temperature some degrees above its melting point, orthoclase for instance will melt to a certain extent; in the course of another half hour it will melt still further, and finally it will become entirely liquid.

A third reason is the very viscous character of the liquid which is formed. Cristobalite above its melting point forms a very viscous liquid, and the same is true of the alkali feldspars. They will, however, flow when once melted. Even pitch, as you know, will

[10] This experiment was suggested by Dr. F. E. Wright.

flow gradually, although under a sudden blow it behaves like a brittle solid.

We come now to the cones numbered 5 to 27. These cones are in effect made up by taking as a basis cone 28, which is practically the eutectic of aluminum silicate and silica, and adding thereto varying quantities of a mixture containing 30 molecular per cent of calcium silicate and 70 molecular percent of potassium silicate. In actual practice, they are made up of quartz, kaolin, orthoclase, and marble or calcium carbonate. These cones 5 to 27 belong therefore in the four-component system: SiO_2-Al_2O_3-CaO-K_2O. It is impossible to represent graphically the compositions in a four-component system, together with the temperature, although composition alone may be represented by points within a tetrahedron.

In order to bring out clearly the composition and behavior of these cones 5 to 27, I have tried to make some simplification, in the first place by neglecting the component which is least active, namely, silica. We will consider the *excess* of silica as being a neutral substance which forms the body of the cone.[11] We will take as the other three substances:

1. Calcium silicate, $CaSiO_3$; this is the most highly silicic compound of CaO and SiO_2. It is not present initially in the form of $CaSiO_3$, but in the form of calcium carbonate and silica; but it is an easily formed compound and melts sharply.

2. Aluminum silicate, Al_2SiO_5, the only compound of Al_2O_3 and SiO_2 which is stable at high temperatures. It is present as an integral part of the kaolin used in making the cones. Like calcium silicate, it melts sharply.

3. Orthoclase, $KAlSi_3O_8$ or $K_2SiO_3.Al_2SiO_5.4SiO_2$; we take this as the third component in preference to K_2SiO_3 because orthoclase is a stable compound and is one of the actual constituents of which the cones are made. Even though it is rather a slow melting substance, it melts perhaps faster than silica and at a fairly low temperature.

[11] Thin sections of two cones, numbers 12 and 15, which had been heated in a porcelain kiln until No. 12 fell, were made in the Geophysical Laboratory some years ago. Both consisted of glass containing considerable amounts of fragmental quartz, apparently almost unacted upon. The glass contained also a small amount of some very minute crystals which had formed on cooling, perhaps Al_2SiO_5.

In order to understand clearly the principles underlying the behavior of such a three-component system, it will be well to review briefly the relations in some simpler systems.

As you well know, the relations of composition and temperature in such a system can be represented by plotting the various mixtures of the three components as points within an equilateral triangle, and the temperatures upward at right angles to the plane of the triangle. A space model can be constructed in this way which will represent the transformation points and melting points of all possible mixtures.

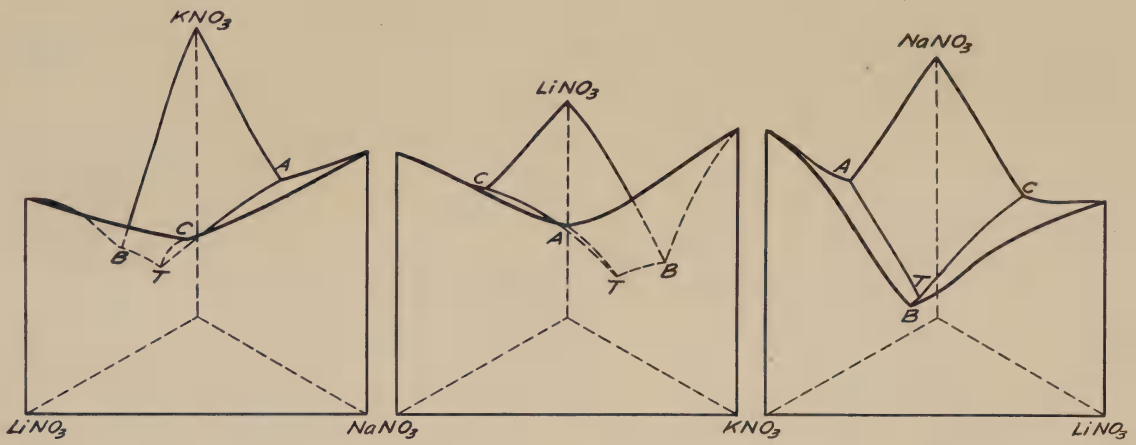
The simplest three-component system is one in which no compounds or solid solutions are formed between the components. There is one mixture of the three which melts completely at a lower temperature than any other mixture, and so forms a "ternary eutectic." A simple system of this kind is illustrated in Figure 4.[12]

The next three-component system in order of complication will be one in which two of the three components form a compound, but no solid solutions occur. A maximum point in the curve of melting temperatures occurs at the composition of the compound, and eutectic mixtures form between the compound and each of its two components. Addition of the third component to the pure compound lowers the melting-point of the latter, and a eutectic mixture occurs between compound and third component. In effect then, this system can be resolved, in its simplest case, into two simple three-component systems side by side, each resembling Figure 4 and having a ternary eutectic. The best example of such a system is that shown in Figure 5.

If, in a system of the type of Figure 5, the third component (the one which forms no compound) be supposed to enter into solid solution in the compound to a limited extent, and conversely, the compound enters into solid solution with the third component, we would have a diagram similar in form to Figure 5 with the possibility again of two ternary eutectics.

Unfortunately, experimental data on the system: orthoclase-$CaSiO_3$-Al_2SiO_5 are very scarce. The two-component system $CaSiO_3$-Al_2SiO_5, however, may be considered a cross-section of the

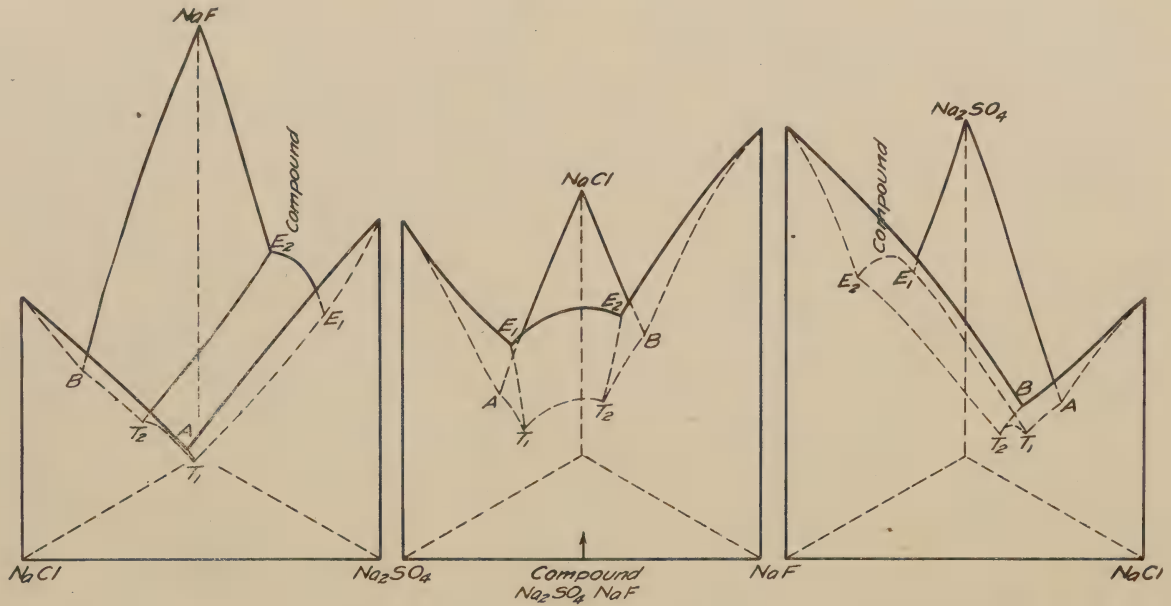
[12] These systems were shown in the form of plaster models.



Three views of the composition-temperature space model for the system $KNO_3 - NaNO_3 - LiNO_3$. Recalculated to molecular percentages from data of Carveth.[13]

KNO_3	m. p. 337°	A	Eutectic KNO_3 and $NaNO_3$ . . m. p. 218°
$NaNO_3$	m. p. 308°	B	Eutectic KNO_3 and $LiNO_3$ . . m. p. 129°
$LiNO_3$	m. p. 253°	C	Eutectic $NaNO_3$ and $LiNO_3$ . . m. p. 204°
		T	Ternary eutectic . . . . . m. p. 119°

[13] See note to Figure 2.



Three views of the composition-temperature space model for the system NaCl—NaF—Na_2SO_4. Data of A Wolters.[14]

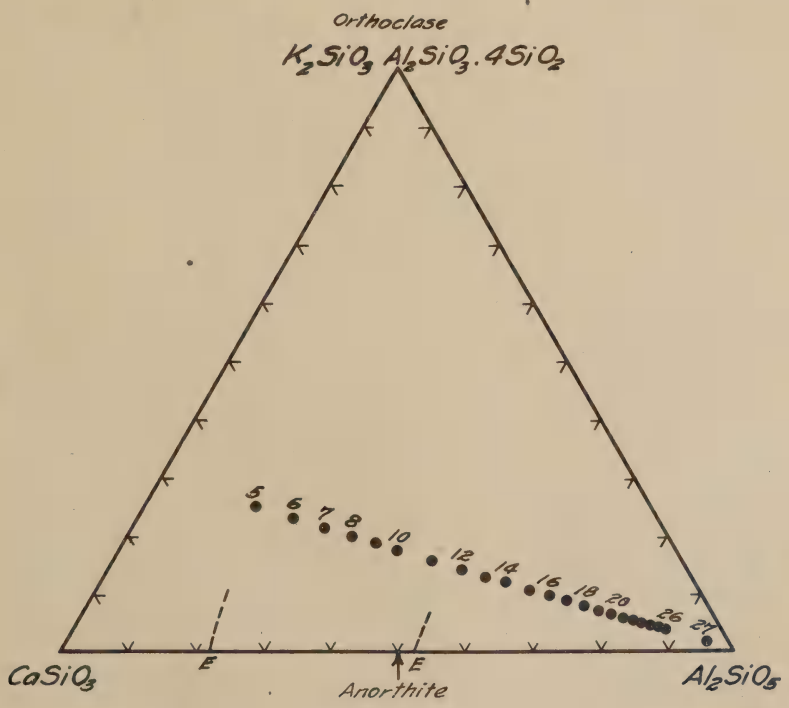
	NaCl	m. p. 797°
	NaF	m. p. 986°
	Na_2SO_4	m. p. 881°
	Compound Na_2SO_4.NaF	m. p. 781°
A	Eutectic: NaCl and Na_2SO_4	m. p. 624°
B	Eutectic: NaCl and NaF	m. p. 674°
E_1	Eutectic: Compound and Na_2SO_4	m. p. 743°
E_2	Eutectic: Compound and NaF	m. p. 773°
T_1	Ternary eutectic; compound, NaCl and Na_2SO_4	m. p. 594°
T_2	Ternary eutectic; compound, NaCl and NaF	m. p. 620°
	Maximum in boundary curve T_1 T_2 (eutectic of compound and NaCl)	m. p. 624°

[14] N. Jahrb. Min. (1910), Beilbd. XXX, 55-96.

system CaO-Al_2O_3-SiO_2, so thoroughly studied by Shepherd and Rankin.[15] In this system there occurs the one compound, anorthite, $CaSiO_3.Al_2SiO_5$, with a binary eutectic on either side. For the rest of the diagram, the evidence of the composition of natural minerals and occasional scraps of experimental evidence all point to the form of fusion diagram described in the preceding paragraph, as being applicable to the system orthoclase-$CaSiO_3$-Al_2SiO_5.

In Figure 6 are shown the compositions of cones 5 to 27 as far as the bases are concerned, omitting excess silica. Since the

Trans. Am. Cer. Soc. Vol. XV Fig. 6 *Sosman.*

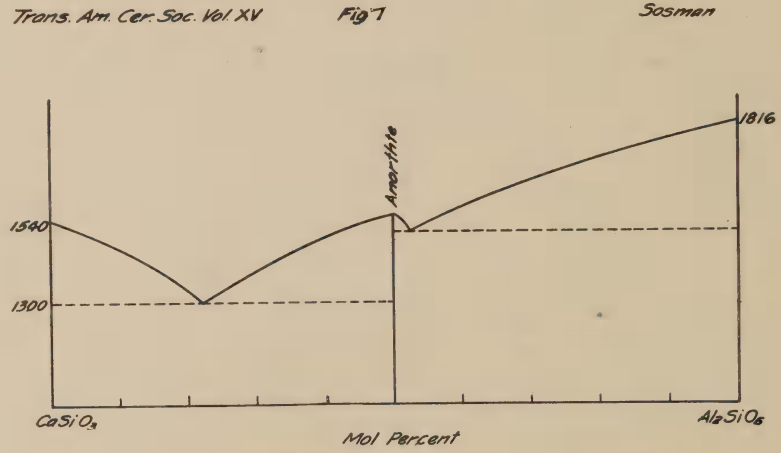


Basal composition of cones 5 to 27, disregarding excess of silica. E, eutectic.

[15] *J. Ind. Eng. Chem.* 3, 211–227. 1911.

proportion of potash to lime is constant, they lie on a straight line across the diagram. The letters E E mark the positions of the eutectics of the two-component system $CaSiO_3$-Al_2SiO_5, and the dotted lines show the probable course of the boundary curves into the three-component system. Figure 7 shows the fusion curve for the two-component system $CaSiO_3$-Al_2SiO_5.[16]

If the properties of these cones are in fact fundamentally controlled by the properties of the three component system orthoclase-$CaSiO_3$-Al_2SiO_5, and if this system has a fusion surface like that indicated by Figures 5–7, then it is possible to make



Form of fusion diagram for the system $CaSiO_3 - Al_2SiO_5$.

certain predictions about these cones. In the first place, the low and well marked eutectic between anorthite and calcium silicate indicates a correspondingly low and well marked ternary eutectic into which orthoclase and orthoclase-bearing anorthite will enter. Cones 5 to 8 should therefore be easily influenced by the rate of heating and should show strongly the tendency to come down in a group.

Cone 10 lies on the line joining anorthite and orthoclase; 9 and 10 should therefore show less markedly the effects of slow heating.

[16] The system $CaSiO_3$-Al_2SiO_5 is not, in the strictest sense, a two-component system, since Al_2O_3 appears as a phase near the Al_2SiO_5 side, due to decomposition. This is a complication of secondary importance, however, in our present considerations.

The anorthite-sillimanite eutectic is quite near anorthite and will influence 11 and 12 in a manner similar to the effect exercised on 5 to 8 by the lower eutectic. The increasing quantity of high melting and skeleton-building sillimanite in the higher cones will cause them to show these influences less and less, until beyond 18 the increasing amount of the sillimanite-cristobalite eutectic requires to be taken into account. These higher cones will appear from another point of view in a later paragraph.

Recorded experience with cones confirms the above predictions in large measure. Seger himself recognized that the lower silicate-alumina cones came too close together: "5, 6 and 7 do not differ much in regard to melting point, ... but I did not desire to do away with the cones 5, 6 and 7 because their numbers correspond to the acidity."[17] Professor Orton said[18] in the discussion of Mr. Geijsbeek's paper in 1904: "I find it almost impossible to make cones 4, 5, 6, 7 and 8 so that one will not sometimes overtake the other." He stated also that he had found the German No. 5 to fall occasionally before No. 4.[19] These instances could no doubt be multiplied from the experience of any user of these cones.

The introduction in Germany of the new "a" series of boro-silicate cones by Simonis in 1908 has probably obviated these difficulties to a considerable extent, since 6a, the highest number of the new series, approximately replaces numbers 4, 5 and 6. But the introductio ı of three additional components (soda, magnesia, and boric acid) complicates the question so much that I have not ventured to discuss their chemical relationships.

Taking up, further, the cones above No. 8, we find numerous experiments which bear out our general predictions. Loeser,[20] for instance, after studying the behavior of the entire series up to about No. 19, states that the groups which show the greatest irregularity are numbers 018 to 012, 1 to 7, and 11 to 12. The effect of slow firing in lowering the falling-temperatures of all the silicate-alumina cones in most common use (comprising numbers

[17] *Gesammelte Schriften*, p. 194.

[18] *Amer. Ceramic Soc. Trans.* 6, 99. 1904.

[19] No. 4 occupies the same position as No. 5 in Figure 6. The ratio of bases is the same in both, but No. 4 contains less excess silica.

[20] *Sprechsaal.* 40, 499–501. 1907.

4 to 20) has been a matter of frequent observation. Zimmer[21] reported that 1 to 9 gave temperatures 25° to 30° lower in a slow fired biscuit kiln than in a smaller trial kiln. Geijsbeek's experiments[22] showed lowerings of 75° to 85° below the nominal values, in long burns with cones 1 to 7. Much more extensive tests were made by Hoffmann[23] covering cones 4 to 35 in laboratory furnaces, and 7 to 17 in commercial kilns. The long continued heating under kiln conditions produced lowerings of from 40° to 110° below the laboratory furnace values. Excellent examples of the control exercised by the low-melting eutectic may be found in the elaborate experiments of Rieke.[24] I will quote one which is of especial interest: "In another burn cones 6 to 10 were heated for some time at 1160° to 1180°. After three-quarters of an hour cone 6 began to bend, and was down after one and one-half hours. After two and one-quarter hours cone 7 followed, and after two and one-half hours, cone 8. After 5 and one-half hours cone 9 was somewhat bent, and superficially glazed, while cone 10 still stood quite erect." It will be remembered that 10 lies on the line between the pure compounds anorthite and orthoclase. The effect of the eutectic in pulling the cones down one after another at a constant temperature is here quite evident.

The investigations of cones 19 to 26 by Simonis in 1907[25] showed that these fall so near together in their temperature indications (1530° to 1566°) that several of them could well be omitted. Numbers 21 to 25 were therefore dropped from the list and are no longer made. One reason for their close approximation in fusing points is evident from the diagram of Figure 6, namely, that the proportion of aluminum silicate varies very little from cone to cone.

These cones, furthermore, lie near the boundary curve for cristobalite, aluminum silicate, and calcium silicate in the three-component system SiO_2-$CaSiO_3$-Al_2SiO_5. In other words, the cristobalite-sillimanite eutectic of Figure 3, lowered by the addition of calcium silicate, probably exercises greater control over the cones at this end of the series than do the eutectics of Figure 6.

[21] *Amer. Ceramic Soc. Trans.* 1, 23–38. 1899.
[22] *Amer. Ceramic Soc. Trans.* 6, 94–99, 1904.
[23] *Sprechsaal.* 44, 143–144. 1911.
[24] *Sprechsaal.* 44, 726–729, 741–744. 1911.
[25] *Sprechsaal.* 40, 71–72. 1907. *Tonind. Ztg.* 31, 146–148, 1907.

What I have said is not intended in any way to decry the usefulness of Seger cones. Their use by hundreds of plants over a period of twenty-five years, and their continued use today side by side with thermoelectric and optical pyrometers, is evidence enough to the man on the outside that Seger cones are practically indispensable to the clay-working industries. But what I have said may serve to emphasize the statement that cones do not measure *temperatures*. They are indicators of heat effects, and as such are very efficient tests for the control of an industrial process. Their use may also be extended to other tests which are in nature of the control of a process, such for instance as the comparison of the softening temperatures of coal ash, where the relative fusibility of different ashes, and not the exact temperature of incipient or complete fusion of a given ash, is the information desired.

Efforts and suggestions have been frequently made with the object of causing the cones to come somewhat nearer to measuring temperature, independent of time and other variables. A recent patent issued to the laboratory of Seger and Cramer[26] covers the use of hollow cones to give more rapid action. Another[27] covers the procedure of first fusing the materials, and then making the cones out of the fused mixtures, in order to do away with the delay in action incident to preliminary reactions among the constituents. But neither of these expedients removes the cone from the influence of its lowest melting eutectic; indeed, the second would place it more under the control of the eutectic than before. Furthermore, it would seem that as a test for controlling a process the slow-acting cone serves a purpose that the quick-acting cone does not, in giving warning that the final stage of a desired heat effect is being approached, and in allowing time for the fire to be regulated accordingly.[28]

If it is desired to obtain a sharp indication of a given temperature, independent of the rate of heating, the fundamental principle is evidently to use only pure compounds or pure eutectics. In spite of numerous statements in silicate literature to the contrary, there are numerous compounds and eutectics among the silicates

[26] German patent 197450, June 1, 1907.
[27] German patent 197698, June 1, 1907.
[28] Discussion in *Trans. Amer. Ceramic Soc.* 8, 163. 1906.

which melt at perfectly definite temperatures, and melt promptly when those temperatures are attained. Furthermore, it is not at all necessary to resort to the slow-melting and very viscous alkali feldspars. A number of these sharp melting compounds are in common use in the Geophysical Laboratory for calibration of thermoelements and occasionally for the direct indication of temperatures. The principal objection to their general use is the necessity of employing very pure chemicals, and of keeping them pure when the mixtures are made. Further research will reveal an increasing number of such compounds and mixtures, and will no doubt show the way toward their application industrially for the measurement of temperature.

The Chairman: Gentlemen, I presume there are quite a number of you who want to ask questions or discuss in some way this exceedingly valuable paper. We will have to get to it at once and not lose any time.

Mr. Purdy: It is beyond the depth of most of us; I think all we can do is to congratulate the author on his fine presentation of the subject and thank him, and I make this motion.

(Motion seconded and adopted.)

Mr. Chairman: In the name of the Society, Dr. Sosman, we thank you for this paper.

COEFFICIENT OF EXPANSION OF PORCELAIN BODY MIXTURES

BY ROSS C. PURDY

The bodies experimented with are those described by Potts and Knollman in "Some Data on the Relative Density of Structure of Bodies, Compounded from Feldspar, Clay and Flint," page 285, this volume.

The apparatus and methods of measurement used was the same as described by Boeck, p. 470, Vol. XIV, *Trans. Amer. Cer. Soc.*

It has been thought best to merely present the data obtained in curve form rather than to give the data themselves, for they are considered as having relative value only, not absolute. Then too, time and space does not permit of a thorough analysis of these data.

OBSERVATIONS

1. It should be noted that in all mixtures containing 30 or more percent of flint, the bodies expand with rising temperatures with regular increment producing practically a straight line curve from room temperature up to 500 C.; that at 500 C. there is an increase in the amount of expansion per degree rise in temperature which continues until the temperature reaches about 600 C.; and that at about 600 C. there is a decided decrease in the rate of expansion, causing the curves to show a decided break at about 600°C.

2. These changes in the rate of expansion noted in observation (1) seem to be due entirely to the flint content, the higher the content of flint the more pronounced the changes in rate of expansion.

3. The rate of expansion with increasing temperature of bodies containing less than 30 percent flint is changed but very slightly at 500 and 600°C.

4. In general terms the rate of increase and the total expansion obtained increase with increase of flint content.

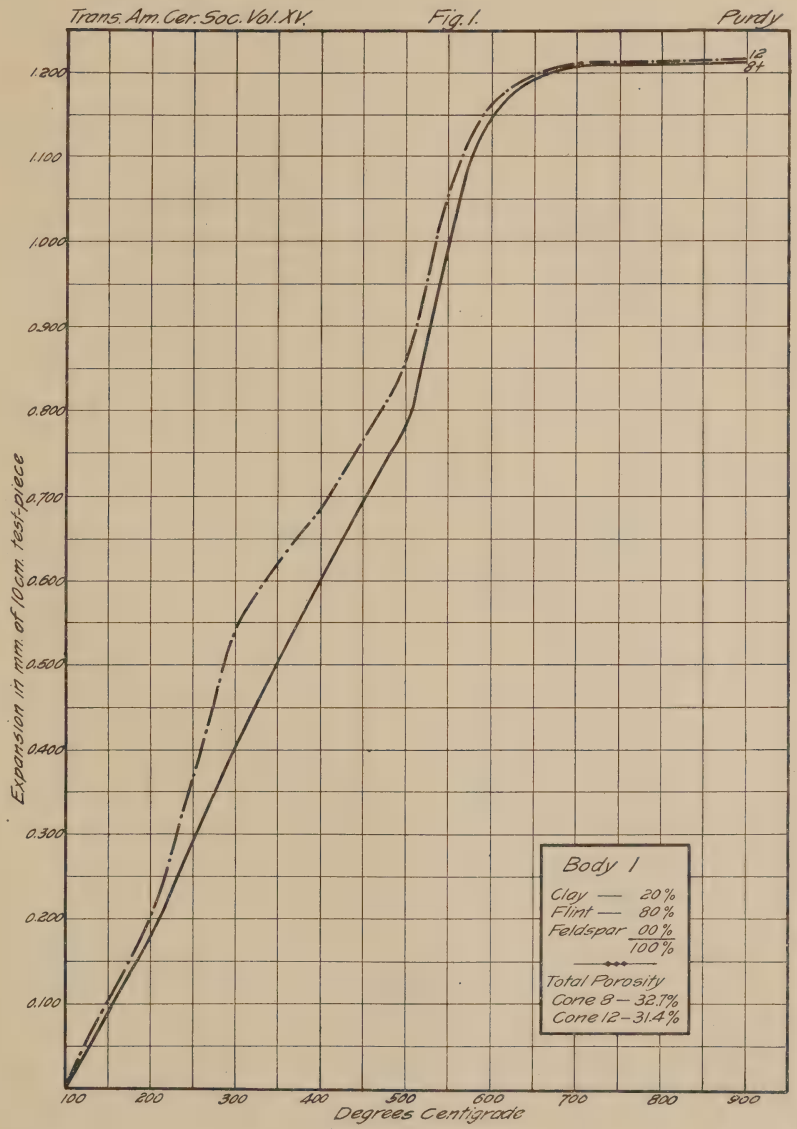
5. The least rate of increase in expansion per degree rise in temperature is formed in the bodies having the lowest flint content

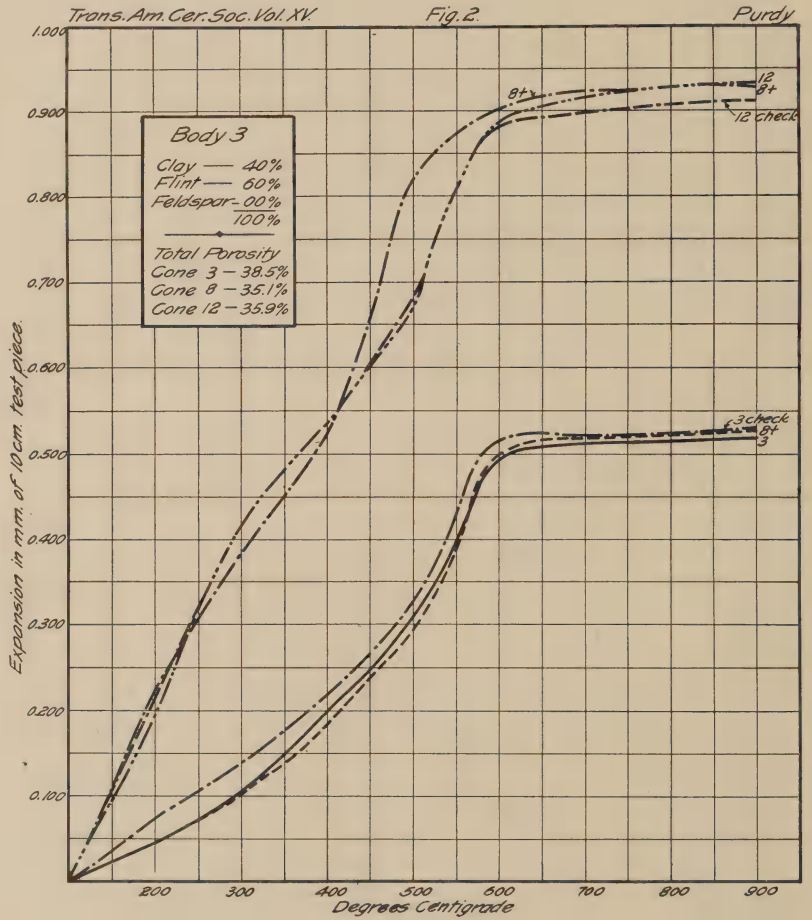
and containing from 10 to 25 percent of feldspar. These also had the lowest total expansion.

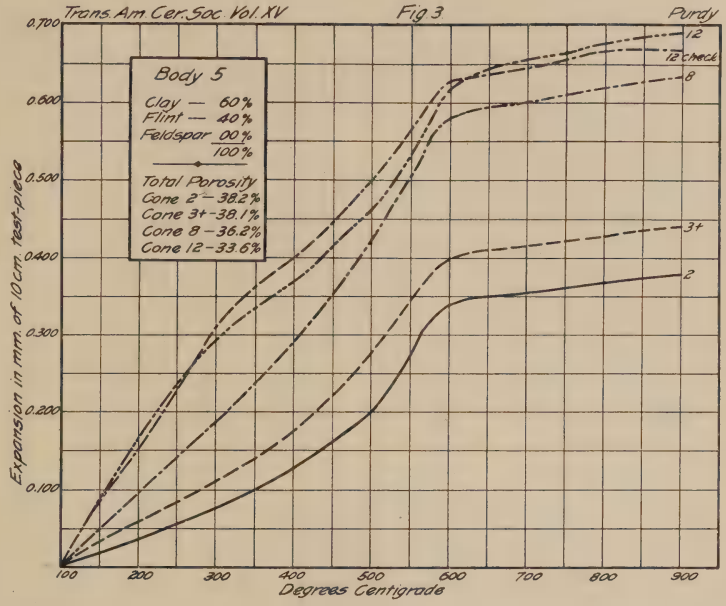
6. Increase in feldspar content increases the rate of expansion, hence the total expansion, but does not interfere with the changes in rate produced by flint.

7. It is not safe to state in certain terms just what effect was produced by the biscuit heat treatment (the heat treatment to which the trial pieces were subjected in burning); but in general it is observed that difference in heat has the greatest effect in bodies containing 40 and more percent of flint, and shows the least effect in the low flint bodies with 10 to 35 percent feldspar.

8. Contrary to the theory set forth by Purdy and Potts, there does not seem to be a constant relation between total porosity and coefficient of expansion. Whether there is any such relation between volume of open pores and the coefficient of expansion is not disclosed by the present data.


Trans. Am. Cer. Soc. Vol. XV.
Fig. 1.
Purdy
1.200
1.100
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
Expansion in mm of 10 cm test-piece
100
200
300
400
500
600
700
800
900
Degrees Centigrade
12
8
Body 1
Clay — 20%
Flint — 80%
Feldspar 00%
100%
Total Porosity
Cone 8 — 32.7%
Cone 12 — 31.4%


Trans. Am. Cer. Soc. Vol. XV.
Fig. 2.
Purdy
Body 3
Clay — 40%
Flint — 60%
Feldspar - 00%
100%
Total Porosity
Cone 3 — 38.5%
Cone 8 — 35.1%
Cone 12 — 35.9%
8+
12
8+
12 check
3 check
8+
3
Expansion in m.m. of 10 cm. test piece
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
200
300
400
500
600
700
800
900
Degrees Centigrade


Trans. Am Cer. Soc. Vol. XV
Fig 3
Purdy
Body 5
Clay — 60%
Flint — 40%
Feldspar 00%
100%
Total Porosity
Cone 2 — 38.2%
Cone 3+ - 38.1%
Cone 8 — 36.2%
Cone 12 — 33.6%
12
12 check
8
3+
2
Expansion in mm of 10 cm test-piece
0.700
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade

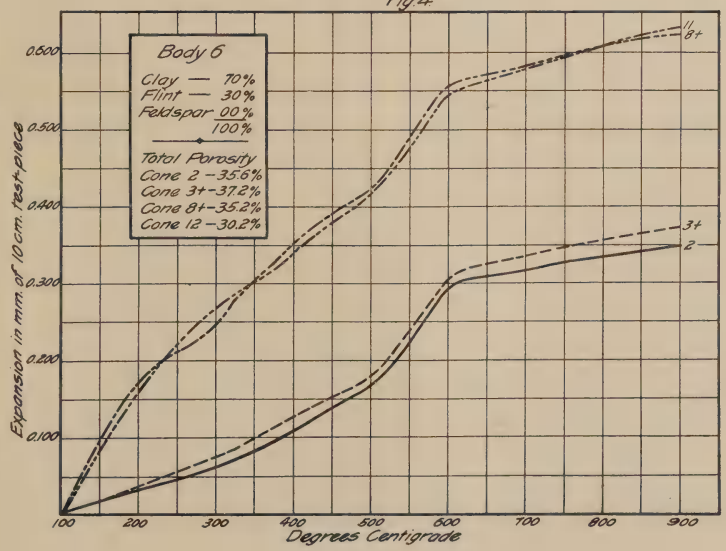
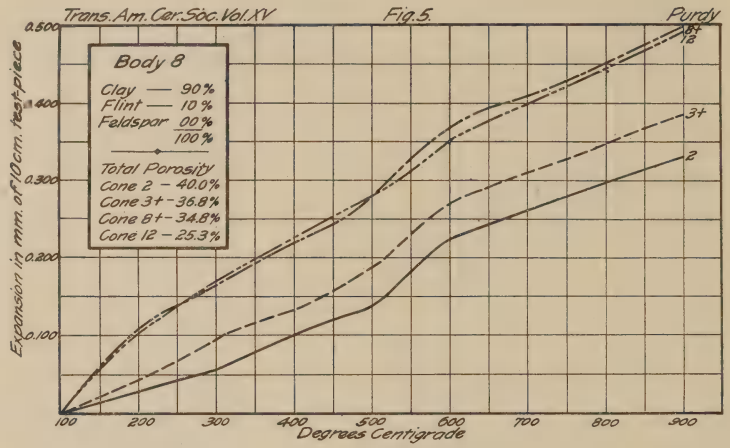


Fig 4
Body 6
Clay — 70%
Flint — 30%
Feldspar 00%
100%
Total Porosity
Cone 2 — 35.6%
Cone 3+ - 37.2%
Cone 8+ - 35.2%
Cone 12 — 30.2%
11
8+
3+
2
Expansion in mm of 10 cm test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade


Trans. Am. Cer. Soc. Vol. XV
Fig. 5.
Purdy
Body 8
Clay — 90%
Flint — 10%
Feldspar 00%
100%
Total Porosity
Cone 2 – 40.0%
Cone 3+ – 36.8%
Cone 8+ – 34.8%
Cone 12 – 25.3%
Expansion in mm. of 10 cm. test-piece
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade
12
8+
3+
2

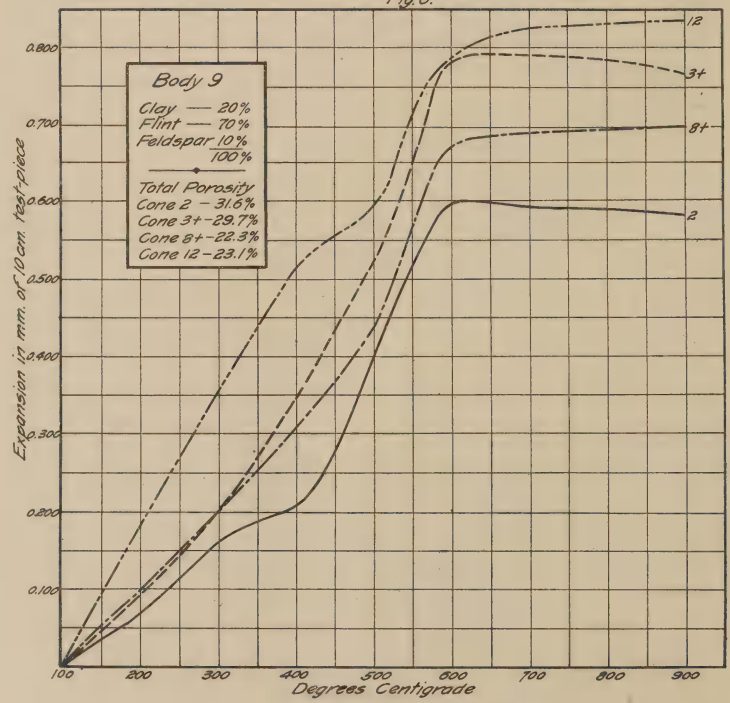


Fig. 6.
Body 9
Clay — 20%
Flint — 70%
Feldspar 10%
100%
Total Porosity
Cone 2 – 31.6%
Cone 3+ – 29.7%
Cone 8+ – 22.3%
Cone 12 – 23.1%
Expansion in mm. of 10 cm. test-piece
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade
12
3+
8+
2

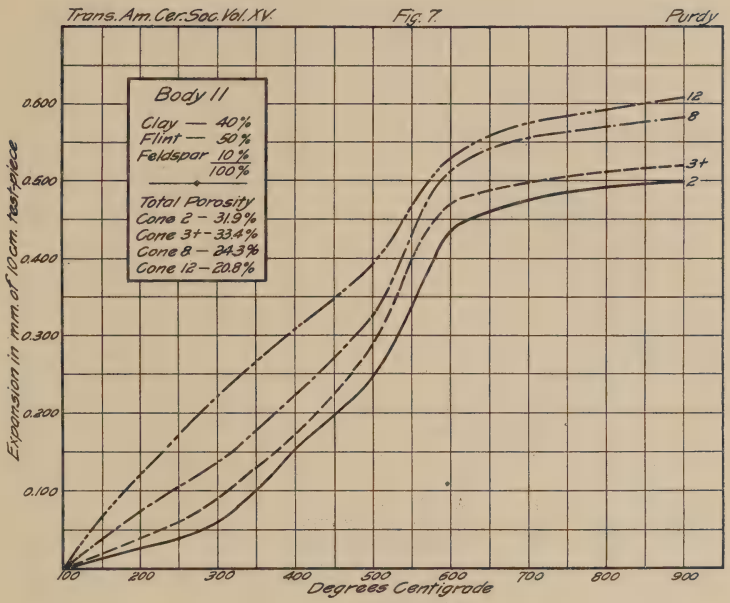
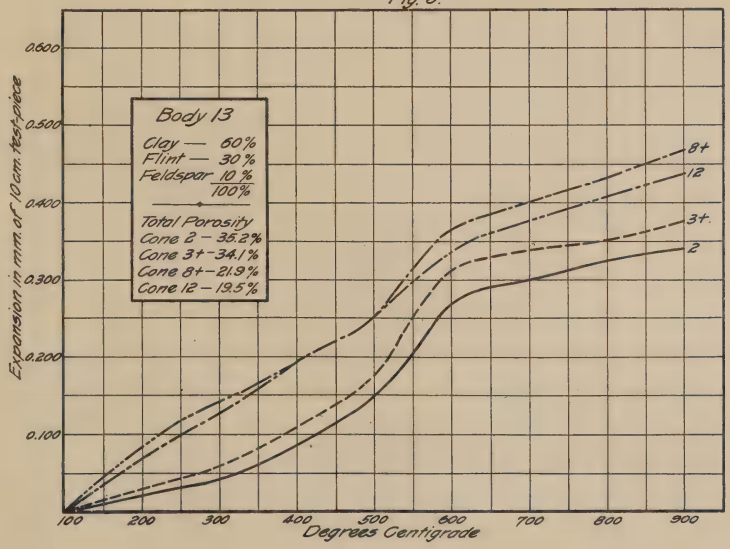
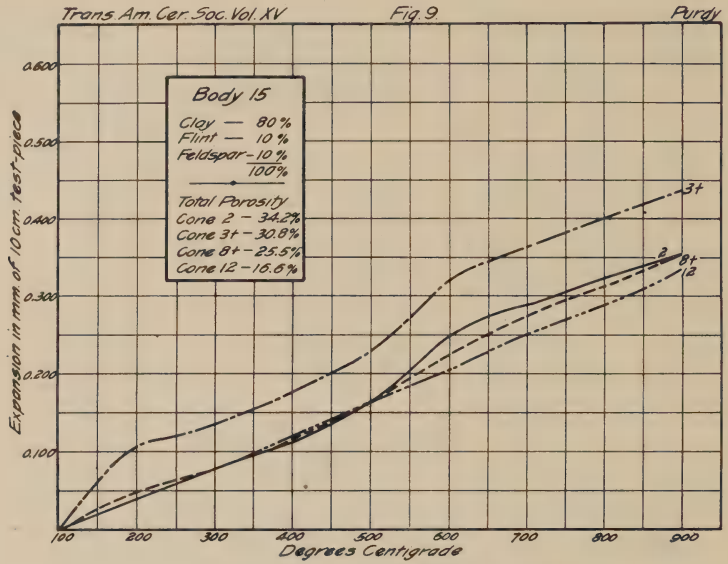

Trans. Am. Cer. Soc. Vol. XV.
Fig. 7.
Purdy
Body 11
Clay — 40%
Flint — 50%
Feldspar 10%
100%
Total Porosity
Cone 2 – 31.9%
Cone 3+ – 33.4%
Cone 8 – 24.3%
Cone 12 – 20.8%
12
8
3+
2
0.600
0.500
0.400
0.300
0.200
0.100
Expansion in mm. of 10 cm. test piece
100
200
300
400
500
600
700
800
900
Degrees Centigrade

Fig. 8.


Body 13
Clay — 60%
Flint — 30%
Feldspar 10%
100%
Total Porosity
Cone 2 – 35.2%
Cone 3+ – 34.1%
Cone 8+ – 21.9%
Cone 12 – 19.5%
8+
12
3+
2
0.600
0.500
0.400
0.300
0.200
0.100
Expansion in mm. of 10 cm. test piece
100
200
300
400
500
600
700
800
900
Degrees Centigrade


Trans. Am. Cer. Soc. Vol. XV
Fig. 9
Purdy
Body 15
Clay — 80%
Flint — 10%
Feldspar - 10%
100%
Total Porosity
Cone 2 - 34.2%
Cone 3+ - 30.8%
Cone 8+ - 25.5%
Cone 12 - 16.6%
3+
2
8+
12
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade

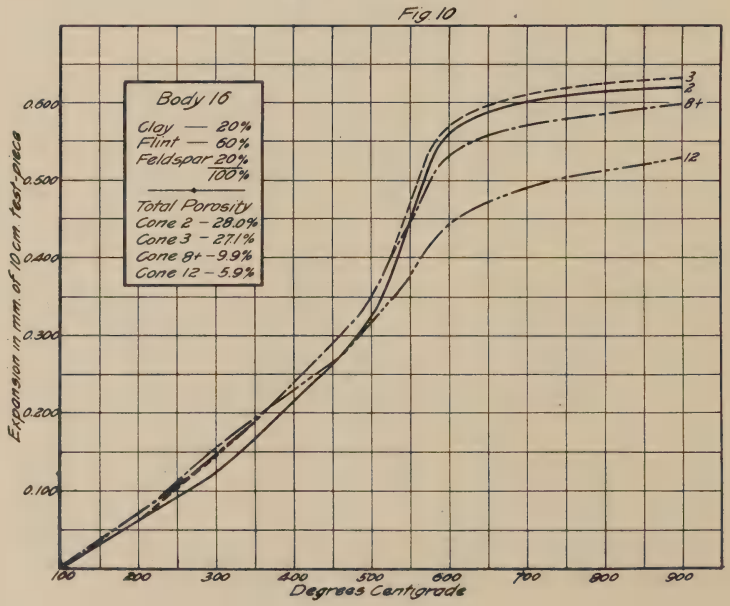
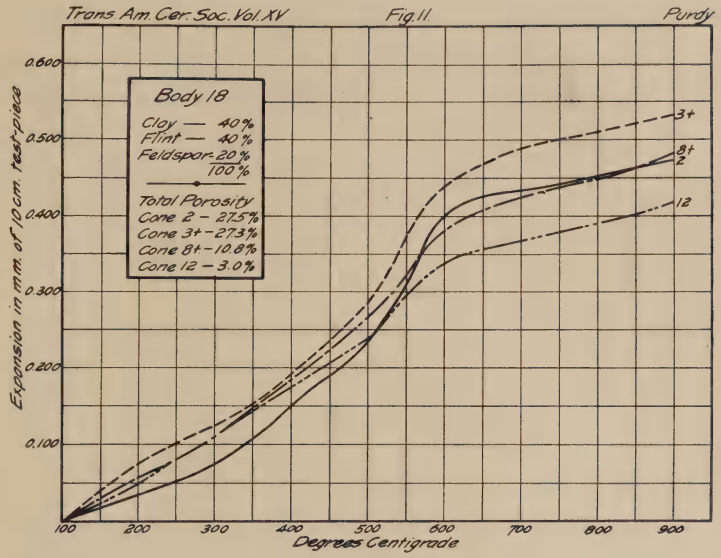


Fig. 10
Body 16
Clay — 20%
Flint — 60%
Feldspar 20%
100%
Total Porosity
Cone 2 - 28.0%
Cone 3 - 27.1%
Cone 8+ - 9.9%
Cone 12 - 5.9%
3
2
8+
12
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade


Trans. Am. Cer. Soc. Vol. XV
Fig. 11
Purdy
Body 18
Clay — 40%
Flint — 40%
Feldspar 20%
100%
Total Porosity
Cone 2 – 27.5%
Cone 3+ – 27.3%
Cone 8+ – 10.8%
Cone 12 – 3.0%
3+
8+
2
12
0.600
0.500
0.400
0.300
0.200
0.100
Expansion in mm. of 10 cm. test piece
100
200
300
400
500
600
700
800
900
Degrees Centigrade

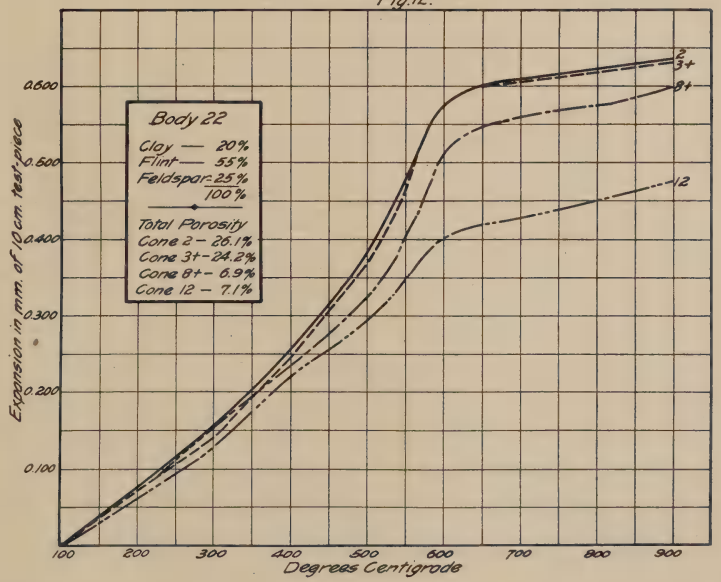
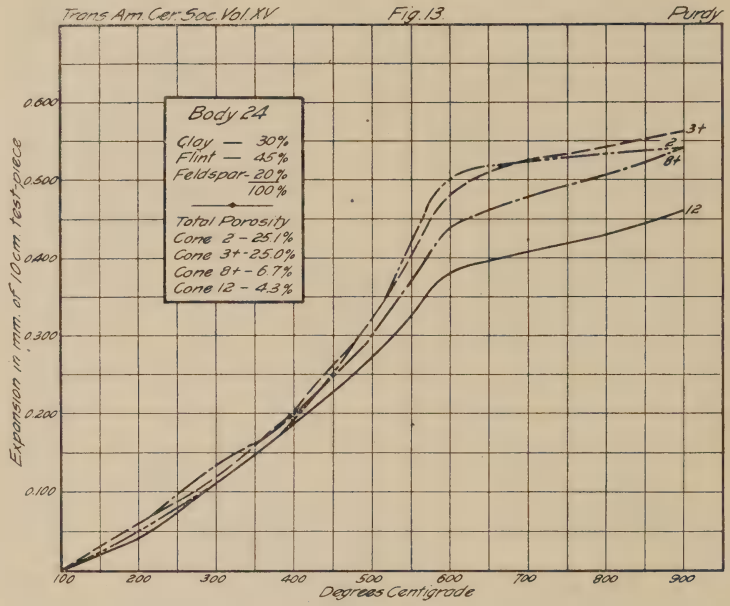


Fig. 12.
Body 22
Clay — 20%
Flint — 55%
Feldspar 25%
100%
Total Porosity
Cone 2 – 26.1%
Cone 3+ – 24.2%
Cone 8+ – 6.9%
Cone 12 – 7.1%
2
3+
8+
12
0.600
0.500
0.400
0.300
0.200
0.100
Expansion in mm. of 10 cm. test piece
100
200
300
400
500
600
700
800
900
Degrees Centigrade


Trans. Am. Cer. Soc. Vol. XV
Fig. 13.
Purdy
Body 24
Clay — 30%
Flint — 45%
Feldspar — 20%
100%
Total Porosity
Cone 2 - 25.1%
Cone 3+ - 25.0%
Cone 8+ - 6.7%
Cone 12 - 4.3%
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade
3+
2
8+
12

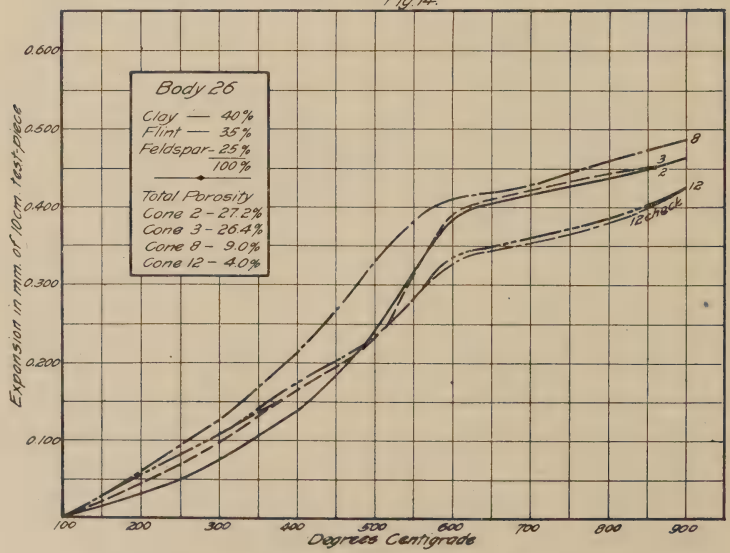
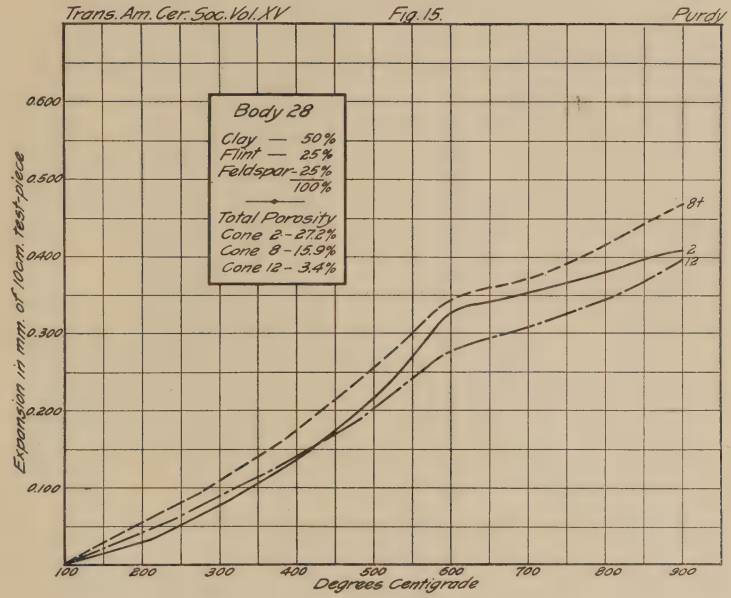


Fig. 14.
Body 26
Clay — 40%
Flint — 35%
Feldspar — 25%
100%
Total Porosity
Cone 2 - 27.2%
Cone 3 - 26.4%
Cone 8 - 9.0%
Cone 12 - 4.0%
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade
8
3
2
12
12 check


Trans. Am. Cer. Soc. Vol. XV
Fig. 15.
Purdy
Body 28
Clay — 50%
Flint — 25%
Feldspar - 25%
100%
Total Porosity
Cone 2 - 27.2%
Cone 8 - 15.9%
Cone 12 - 3.4%
8†
2
12
0.600
0.500
0.400
0.300
0.200
0.100
Expansion in mm. of 10cm. test-piece
100
200
300
400
500
600
700
800
900
Degrees Centigrade

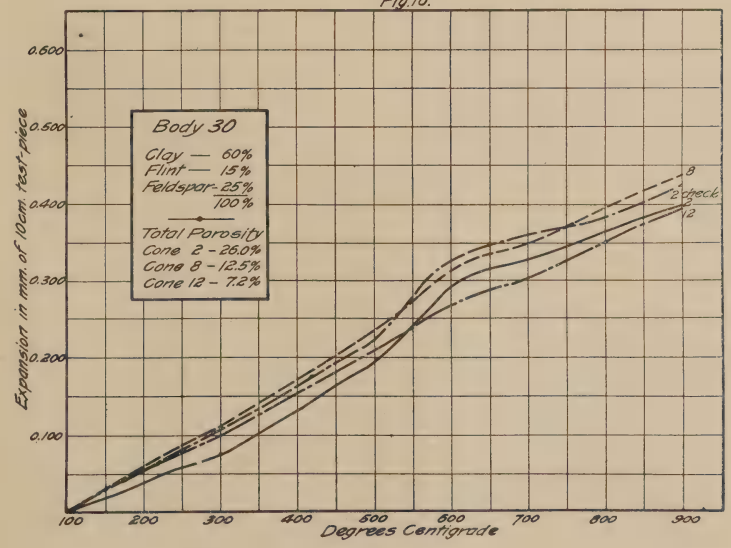
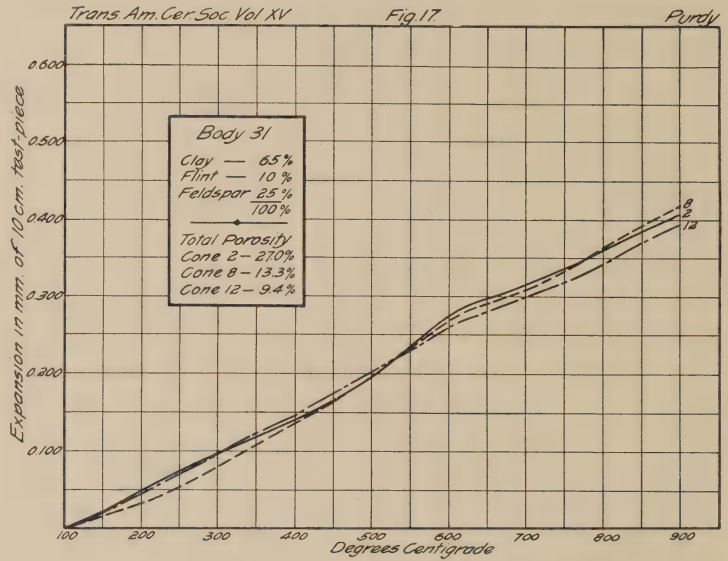


Fig. 16.
Body 30
Clay — 60%
Flint — 15%
Feldspar - 25%
100%
Total Porosity
Cone 2 - 26.0%
Cone 8 - 12.5%
Cone 12 - 7.2%
8
2 check
2
12
0.600
0.500
0.400
0.300
0.200
0.100
Expansion in mm. of 10cm. test-piece
100
200
300
400
500
600
700
800
900
Degrees Centigrade


Trans. Am. Cer. Soc. Vol XV
Fig. 17
Purdy
Body 31
Clay — 65%
Flint — 10%
Feldspar 25%
100%
Total Porosity
Cone 2 – 27.0%
Cone 8 – 13.3%
Cone 12 – 9.4%
8
2
12
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade

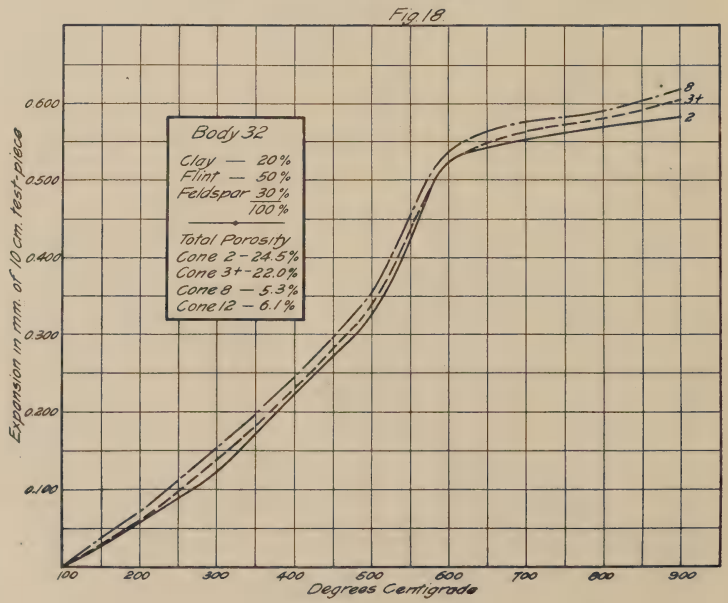
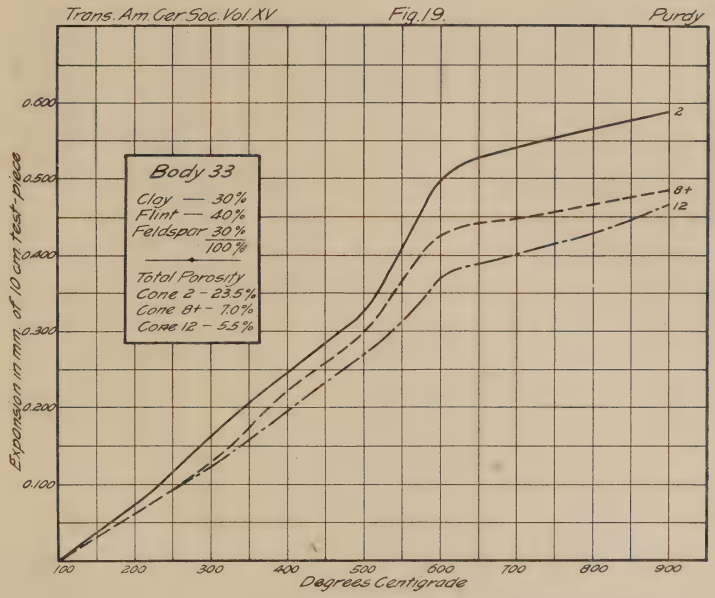


Fig. 18
Body 32
Clay — 20%
Flint — 50%
Feldspar 30%
100%
Total Porosity
Cone 2 – 24.5%
Cone 3+ – 22.0%
Cone 8 — 5.3%
Cone 12 – 6.1%
8
3+
2
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade


Trans. Am. Cer. Soc. Vol. XV
Fig. 19.
Purdy
Body 33
Clay — 30%
Flint — 40%
Feldspar 30%
100%
Total Porosity
Cone 2 - 23.5%
Cone 8+ - 7.0%
Cone 12 - 5.5%
2
8+
12
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade

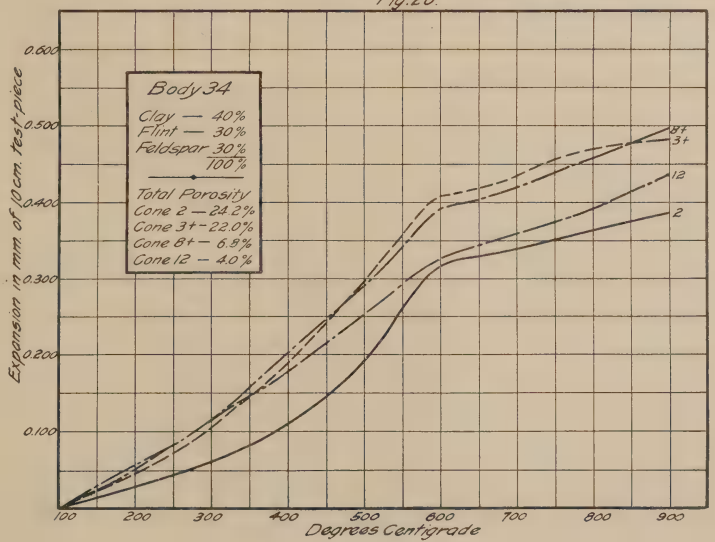


Fig. 20.
Body 34
Clay — 40%
Flint — 30%
Feldspar 30%
100%
Total Porosity
Cone 2 — 24.2%
Cone 3+ - 22.0%
Cone 8+ — 6.9%
Cone 12 — 4.0%
8+
3+
12
2
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade

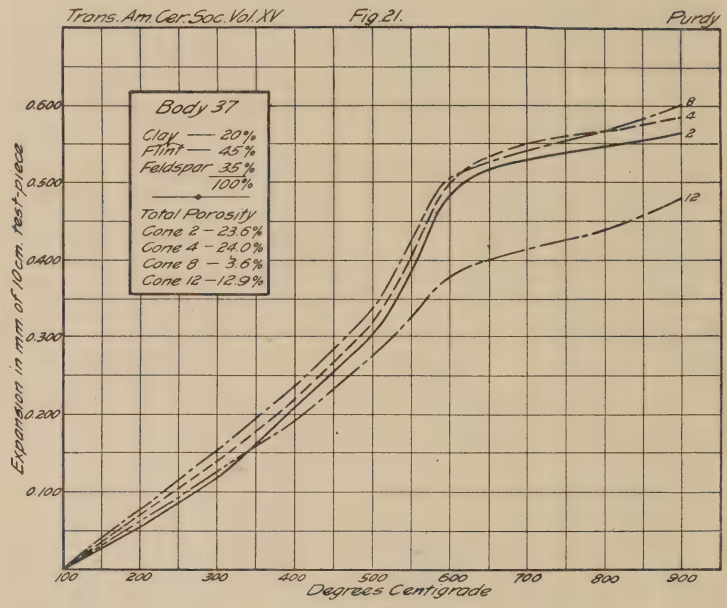
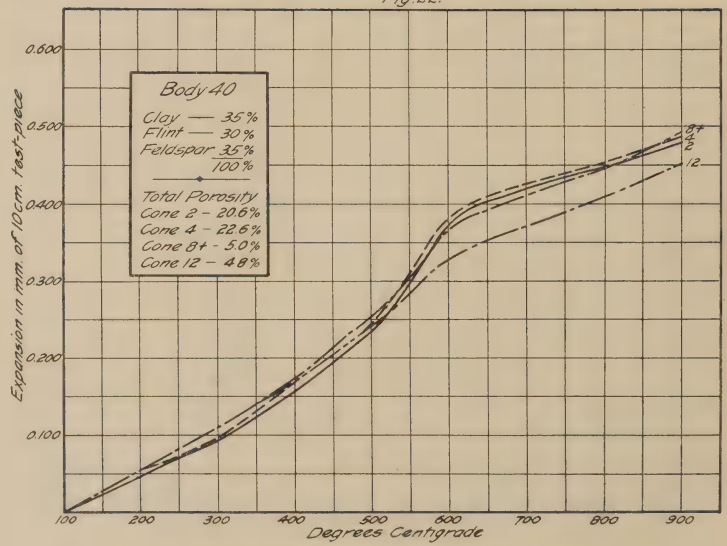

Trans. Am. Cer. Soc. Vol. XV
Fig. 21.
Purdy
Body 37
Clay — 20%
Flint — 45%
Feldspar 35%
100%
Total Porosity
Cone 2 – 23.6%
Cone 4 – 24.0%
Cone 8 – 3.6%
Cone 12 – 12.9%
8
4
2
12
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade

Fig. 22.


Body 40
Clay — 35%
Flint — 30%
Feldspar 35%
100%
Total Porosity
Cone 2 – 20.6%
Cone 4 – 22.6%
Cone 8+ – 5.0%
Cone 12 – 4.8%
8+
4
2
12
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade

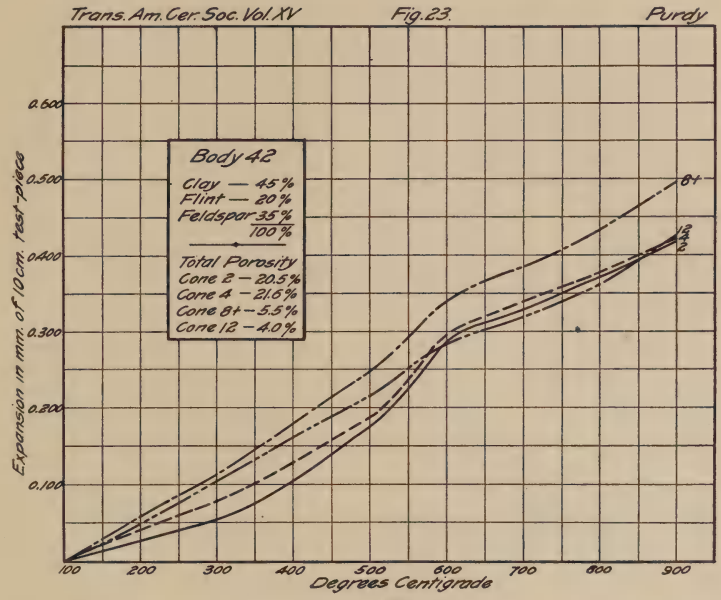
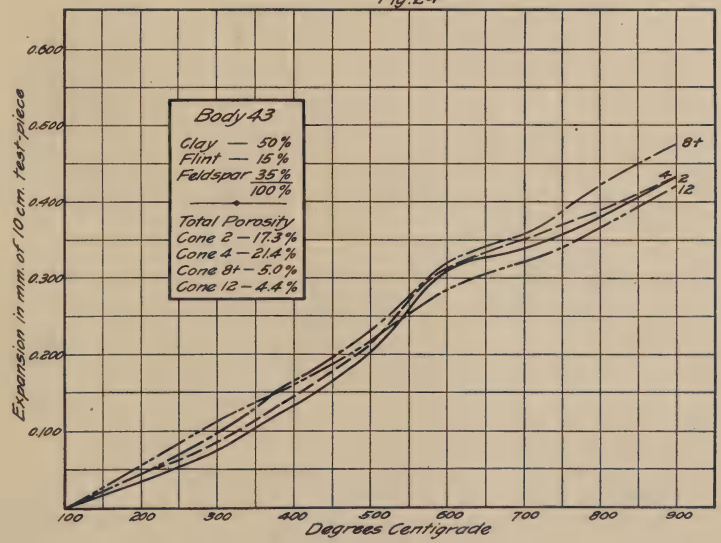

Trans. Am. Cer. Soc. Vol. XV
Fig. 23.
Purdy
Body 42
Clay — 45%
Flint — 20%
Feldspar 35%
100%
Total Porosity
Cone 2 — 20.5%
Cone 4 — 21.6%
Cone 8+ — 5.5%
Cone 12 — 4.0%
8+
4
2
12
0.600
0.500
0.400
0.300
0.200
0.100
Expansion in mm. of 10 cm. test-piece
100
200
300
400
500
600
700
800
900
Degrees Centigrade

Fig. 24


Body 43
Clay — 50%
Flint — 15%
Feldspar 35%
100%
Total Porosity
Cone 2 — 17.3%
Cone 4 — 21.4%
Cone 8+ — 5.0%
Cone 12 — 4.4%
8+
4
2
12
0.600
0.500
0.400
0.300
0.200
0.100
Expansion in mm. of 10 cm. test-piece
100
200
300
400
500
600
700
800
900
Degrees Centigrade

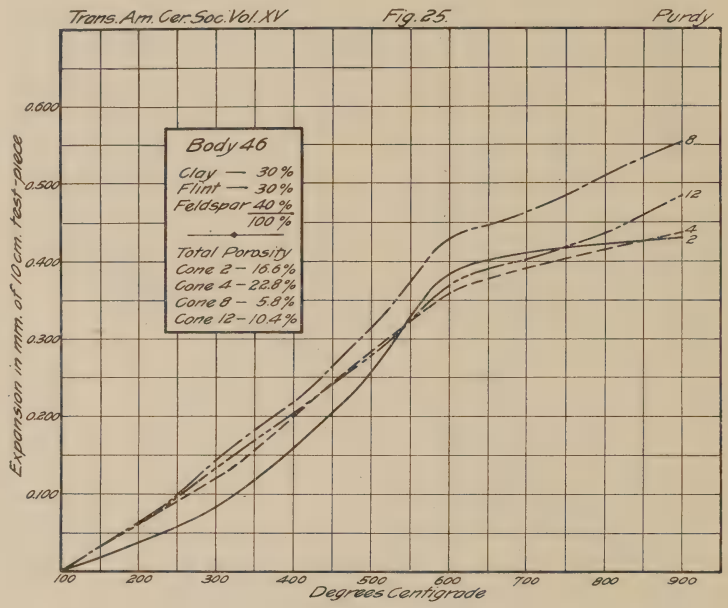

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Fig. 25.
Purdy
Body 46
Clay — 30%
Flint — 30%
Feldspar 40%
100%
Total Porosity
Cone 2 – 16.6%
Cone 4 – 22.8%
Cone 8 – 5.8%
Cone 12 – 10.4%
8
12
4
2
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade

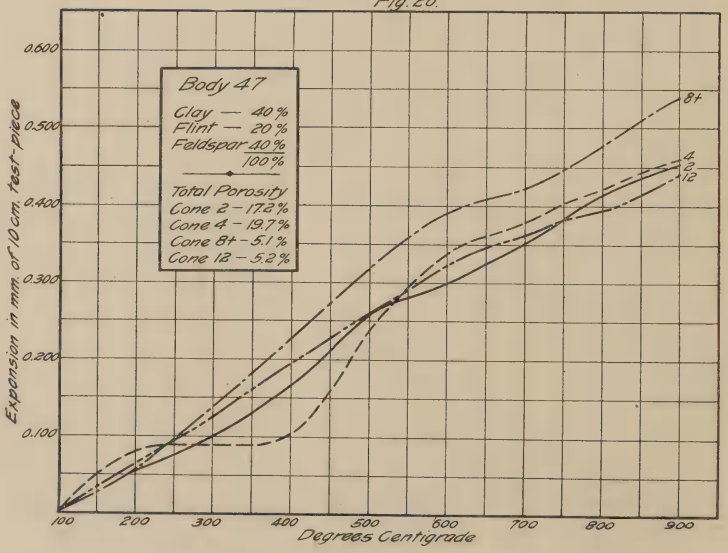
Fig. 26.
Body 47
Clay — 40%
Flint — 20%
Feldspar 40%
100%
Total Porosity
Cone 2 – 17.2%
Cone 4 – 19.7%
Cone 8+ – 5.1%
Cone 12 – 5.2%
8+
4
2
12
Expansion in mm. of 10 cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade

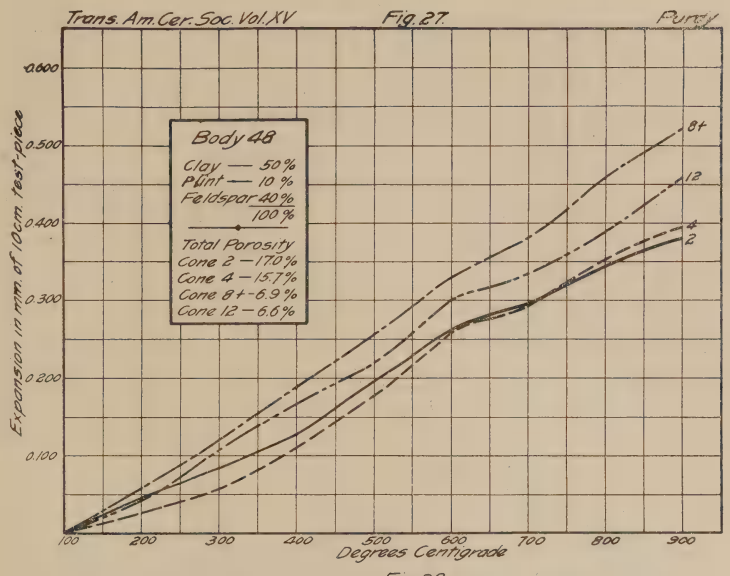
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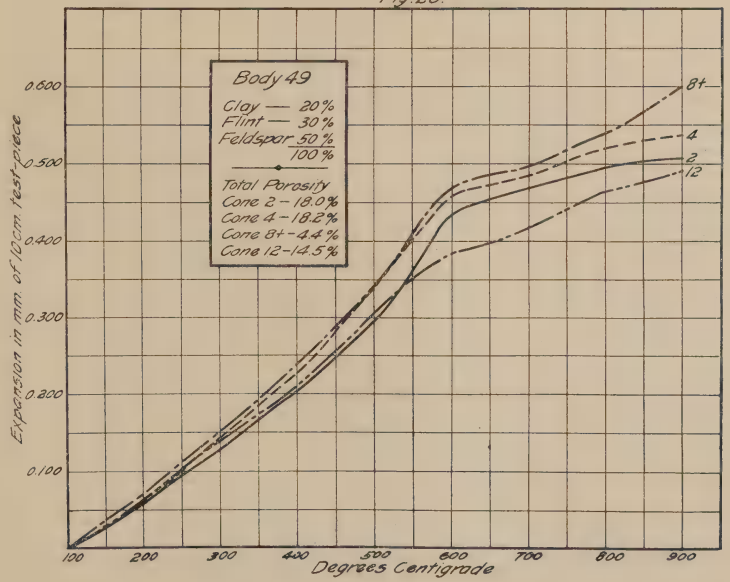
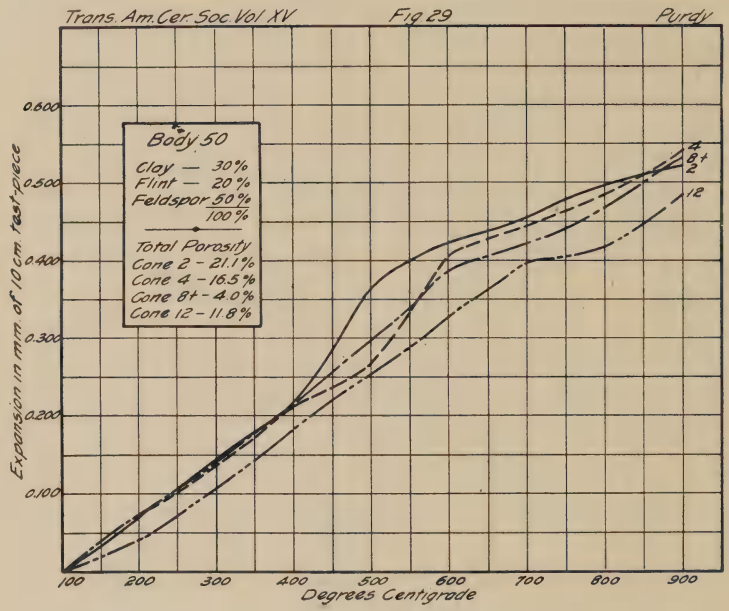
Fig. 27.
Body 48
Clay — 50%
Flint — 10%
Feldspar 40%
100%
Total Porosity
Cone 2 — 17.0%
Cone 4 — 15.7%
Cone 8+ — 6.9%
Cone 12 — 6.6%
8+
12
4
2
Expansion in mm. of 10cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade

Fig. 28.


Body 49
Clay — 20%
Flint — 30%
Feldspar 50%
100%
Total Porosity
Cone 2 — 18.0%
Cone 4 — 18.2%
Cone 8+ — 4.4%
Cone 12 — 14.5%
8+
4
2
12
Expansion in mm. of 10cm. test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade


Trans. Am. Cer. Soc. Vol. XV
Fig. 29
Purdy
Body 50
Clay — 30%
Flint — 20%
Feldspar 50%
100%
Total Porosity
Cone 2 - 21.1%
Cone 4 - 16.5%
Cone 8+ - 4.0%
Cone 12 - 11.8%
Expansion in mm of 10 cm test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade
4
8+
2
12

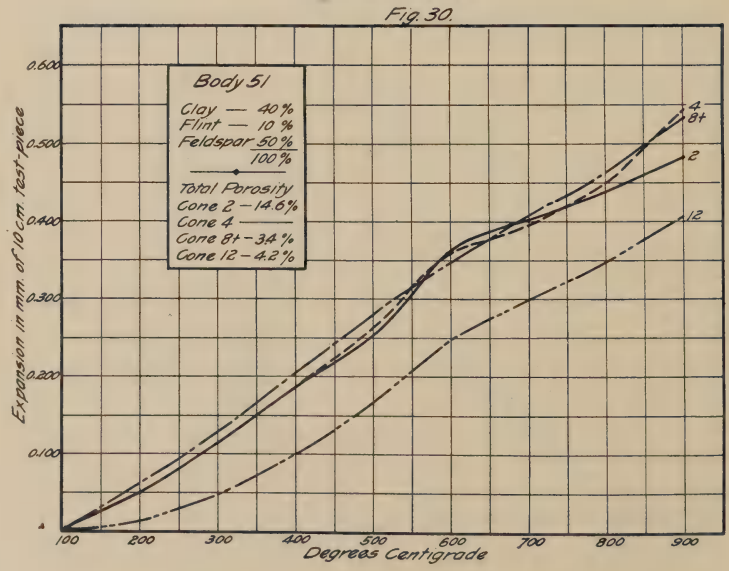


Fig. 30.
Body 51
Clay — 40%
Flint — 10%
Feldspar 50%
100%
Total Porosity
Cone 2 - 14.6%
Cone 4 —
Cone 8+ - 3.4%
Cone 12 - 4.2%
Expansion in mm of 10 cm test-piece
0.600
0.500
0.400
0.300
0.200
0.100
100
200
300
400
500
600
700
800
900
Degrees Centigrade
4
8+
2
12

DISCUSSION

Dr. Sosman: I want to inquire whether any microscopic analyses have been made in connection with this series of experiments?

Mr. Purdy: No sir, we have not.

Dr. Sosman: It seems to me that it would be very interesting to compare the microscopic analyses with these results. Though mineral quartz is known to expand at an increasing rate up to a temperature of 575°, at that point there is a sudden change in the crystal, and above 575°, the coefficient of expansion is negative. If quartz is present in the mixtures on which you obtained those curves, it seems to me that this phenomenon would explain that peculiar form of curve.

Mr. Purdy: May I ask if quartz would change that rapidly? We did not take a very long time in heating and cooling these trials; we could do three expansions in a day, so we did not take over three hours per test piece.

Dr. Sosman: It is not a question of hours; it will change almost instantly.

Prof. Parmelee: One case came under my observation recently. There is a brick plant using quite a silicious clay, and during the progress of burning, they ran short of fuel. They were compelled to let the kiln cool down and when the fuel arrived, the fires were started again. When they opened the kiln, they found an extraordinarily large number of cracked brick, and I have always believed that the difficulty was due to this cause which has been mentioned, namely that the firing had been carried up to a point at which the rapid expansion of the quartz had taken place, that the material had not burned hard enough to secure strength, and on cooling again, it followed practically the same sharp curve it did during firing. On re-firing, it was subjected again to the same strain, and consequently the brick cracked in unusually large numbers.

Mr. Moore: Mr. Purdy has mentioned the fact that he fired, in these investigations, from a low temperature up to 900° because it had been plain that crazing may occur at the lower temperature. I have not seen crazing occur at that temperature, but I have

seen shooting occur at a temperature of about, as nearly as I can guess, 400°. I had occasion one time, to take the door of a trial kiln down in which I had some trials with glazes on a very sandy body. The glaze was perfect when the door of the kiln was taken down, but while I was watching, those glazes began to shiver and continued until they left the body bare, and at a comparatively low temperature.

Prof. Orton: Mr. Chairman, I would like to ask Dr. Sosman a question: every time you heat a quartz crystal up to 575°, does it change over to cristobalite?

Dr. Sosman: No, it is not a question of the change to cristobalite; this is a case of two different kinds of quartz; the ordinary form changes to high-temperature quartz or beta-quartz at 575°, and this with falling temperature comes back to ordinary quartz again.

Prof. Orton: At what temperature does the cristobalite change occur?

Dr. Sosman: At about 1200° or higher. Dr. Fenner found only an uncertain trace of cristobalite in quartz heated for a long time at 1200°. At higher temperatures the change progresses more rapidly.

Prof. Orton: Then if you have the quartz crystal heated to a thousand degrees and it cools off, it goes back to the low temperature form when it gets to 575°?

Dr. Sosman: Yes sir, all the properties change in that same sharp manner, and that temperature, it seems to me, is one of the most important natural temperatures. In the heating of granite (or any rock containing quartz) you will find at that temperature a sudden change in the quartz, and of course the sudden expansion due to that change will crack the granite to pieces. If you heat it up the second time, the grains will push a little further apart, and each repeated heating will increase the granite a little more in volume.

Prof. Orton: That would show then that every time a silica brick is heated past this 575°, there would be a tendency for its structure to become rotted thereby?

Dr. Sosman: Yes, the more often it passes by 575°, the more it will be broken up.

Prof. Orton: That perhaps accounts for the fact that where they are using silica brick, they find by experience that it does not pay to let the furnace cool down very often.

Dr. Sosman: They might cool it to 600° without harm.

Mr. Frink: In the caps of our glass furnaces, whenever we have a furnace cooling off, there is a temperature, we never knew just what it was, 500 or 600 or 800°, but we knew there was one temperature at which it was quite essential that a man should be there with a wrench in his hand following up the cap or the next time we heated up, we would hump it up in the center. I have seen four or five tons of pig iron piled on top of a cap to try to keep it down, without any result.

Prof. Parmelee: On this particular kiln a pyrometer was used. Do I understand you to say, Dr. Sosman, that silica always returns to the same crystaline form?

Dr. Sosman: Yes.

Prof. Parmelee: We have a statement in Bourry that experiments have been tried on quartz crystals and that with repeated firing increasingly large amount of quartz changes crystaline form and that the change is permanent.

Dr. Sosman: That is true, at a very high temperature, the form to which it changes being cristobalite.

Prof. Parmelee: The source of Bourry's information is not given but Korl makes a reference to similar set of studies and gives Cramer the credit, so I assume that it comes from the source.

Mr. Purdy: Is there any lag at all in this volume change of quartz at 575°?

Dr. Sosman: I never observed any lag at all. We made some experiments on this volume change, and it occurs very suddenly. The curve comes up in a rounded form which made us suspect at first that it was a time lag, but the volume comes back along the same curve.

Mr. Purdy: In the case of silica bricks, you have coarse grain the same as in granite. Wherever you have large grains, you get a permanent set, that is, the expansion of the individual grains pushes the grains apart. Hence there is a permanent expansion of the volume. In these porcelain bodies however, there is no lag at all; they return to their exact volume, and we spent two weeks

trying to find one of these pieces that would exhibit a lag. Even the body highest in flint and lowest in feldspar exhibited no lag at all. It cooled right back as fast as the furnace would cool, so that the expansion of the quartz left no effect on the volume of the piece so far as we could detect it. I suppose that is because our flint is so fine.

Dr. Sosman: I suppose it is due to the fineness of the grain.

Prof. Potts: How did the curve for number 6 compare with 49? You have the same flint content, the only difference would be in the feldspar and clay.

Mr. Purdy: They run a great deal alike, only that number 6 has a more decided hump than 49.

Prof. Potts: That would lend weight to Dr. Sosman's statement that the change is due to the flint; there is a much greater similarity in these two bodies than there is in the bodies you compared first.

Mr. Purdy: That is only true where we have equal vitrification, where we bring this body up to cone 8 or cone 12 vitrified; then we get curves that are quite similar, but we have that same pronounced hump at 600°C. in all these high flint bodies.

Prof. Potts: I think that hump in every case represents that sudden change.

Prof. Orton: Presumptively then, quartz as quartz is not present in large amounts.

Mr. Purdy: I don't know. They took about a day or a day and a half to cool the kiln in which the bodies were burned, and whether quartz would change to cristobalite and back again, or not, in that day and a half, I don't know.

Dr. Sosman: No, cristobalite, if formed would probably not change back to quartz.

Mr. Purdy: Then we must be dealing with cristobalite.

The Secretary: Cone 2 is supposed to be 1170°C; it depends on how fast you melt it. Cone 10 is 1330°C; that is, if you melt it fast enough; if you melt it over a long period, it is a good deal lower.

Dr. Sosman: These temperatures are not sufficient to transform quartz, when alone, into cristobalite, with any rapidity. Even after heating at as high a temperature as 1600° for 3 or 4 hours, we have found considerable quartz left.

Prof. Orton: Isn't it entirely probable that in these bodies which have been sintered at cone 2 or above that, you are dealing with glassy solutions? Petrographic methods might show the existence of quartz remaining as quartz, but wouldn't they also show bodies that remain glass.

Dr. Sosman: Yes sir.

Prof. Orton: It seems to me then that if you can prevail on Doctor Sosman to do that microscopic work, it would be a good thing; I think it would be interesting.

Prof. Potts: Most of the discussion has dealt with quartz and cristobalite. It seems to me I read recently in a German publication that tridymite belongs in between, about 900 or 970.

Dr. Sosman: There are seven forms of silica known already. There is quartz, which has two forms, one below 575 and one above. 575. Tridymite has two forms, one below 120 and one above 120, and cristobalite has two, one below 220 degrees and one above 220 degrees, and finally there is fused silica glass. The crystalline varieties are in pairs; two quartzes, 2 tridymites, and 2 cristobalites. Cristobalite is the stable form at high temperature; tridymite is an intermediate form, which is stable between 870° and 1470°, and quartz is the stable form at low temperatures. The most of this work on the forms of silica has been done by Dr. C. N. Fenner at the Geophysical Laboratory. A preliminary publication of the results has been made in *Jour. Washington Acad. Sci.*, 1912, **2**, 471-480.

Mr. Barringer: I would like to ask if this curve is really due to quartz, in any of these forms, couldn't you get a side light on the problem by using the fused quartz, the amorphous quartz, and substituting it in one of those bodies? That would wipe out that peak in the curve where the other forms of quartz changed.

Dr. Sosman: It might wipe that out.

Prof. Parmelee: We speak of fused quartz; is that quartz or another form of silica other than quartz?

Dr. Sosman: The names, "fused quartz," and "quartz glass" are unfortunate trade names, but it is not worth while to try to get rid of them. Fused quartz is really fused silica and should be called by that name.

Prof. Orton: If it is put up and down through temperature changes, won't it tend to crystalize again?

Dr. Sosman: Yes, it will, and the higher the temperature the more rapidly it will crystallize. Cristobalite is the usual product of this devitrification.

Mr. Watts: I have noticed in the study of the deformed feldspar-quartz cones, when I undertook to study them by optical pyrometry to see in what stage I was getting my quartz, that there was no evidence after deformation began or had proceeded a little way of free quartz in the quartz-feldspar mixtures. Except when I get a very large content of quartz, it seems to immediately be taken into solution by the feldspar, and I get a glass as evidence. The index of refraction drops away down just as you would expect in a glass. The interesting point was merely that in these deformed feldspar-quartz mixtures, the mixture seems to become a glass, at least the quartz cannot be located, even in the powders, as quartz. It all seems to go way down below 1.545 which I believe is the index of refraction of quartz.

I had in mind also the examination of some porcelain bodies of which I had slides made two years ago, and I would like to say that I will be very glad to furnish those if they would be of any interest to you. I have the ceramic formula, that is, the percentage of quartz, feldspar and clay and lime, and also the type of feldspar that was used in these. I also have a statement of the temperatures at which the firing was done.

THE ELECTRICAL CONDUCTIVITY OF CLAYS AND CLAY SUSPENSIONS

BY A. V. BLEININGER AND C. S. KINNISON

The development of the casting process, of the electrical purification of clay and the study of the effect of soluble salts, makes it frequently necessary to estimate the amount of salts present in clays. This may be done by means of the usual analysis, which is time consuming, or by the determination of the electrical conductivity, a quick method, giving results in a few minutes. This method is based upon the fact that the conductivity is approximately proportional to the concentration of the salt within certain limits. The conductivity of pure liquids is small, that of ordinary distilled water being 10^{-6} reciprocal ohms at 18°. Even the slightest trace of a soluble salt will increase the conductivity very greatly, and proportionally (in very dilute solutions) to the amount of the salt present. As the concentration increases, however, the conductivity relations become more complex and in very strong solutions they do not conform to simple rules. For practical purposes, especially for comparative estimations between substances of about the same magnitude of concentration, the conductivity may well be used for quantitative determinations.

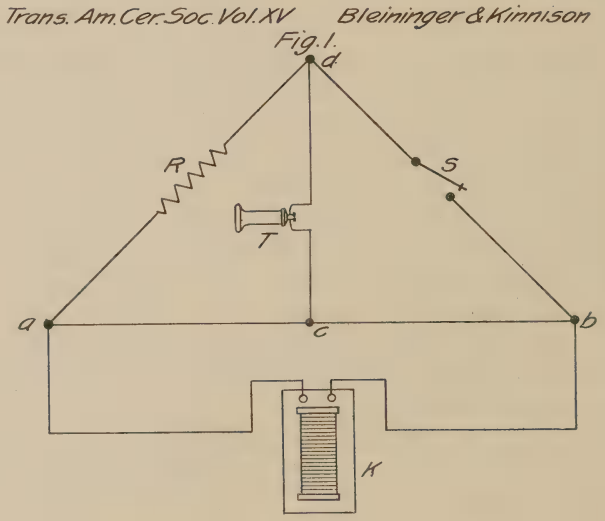
The conductivity of electrolytes increases considerably with rise of temperature. The temperature coefficient for salts is 0.02 to 0.023, for acids and some acid salts 0.009 to 0.016, for caustic alkalies about 0.02 and does not vary much with the dilution. Since conductivity data are usually given for 18°, the specific conductivity C at any other temperature may be calculated from the relation:

$$C_t = C_{18}\,(1 + k\,(t - 18))$$

where k is the temperature coefficient. The increase in conductivity with temperature is not due to an increase in the number of ions, but to an increase in their speed. The latter is made possible by the reduction in internal friction of the solvent with rise of temperature and the resulting diminished resistance in the passage of the ions.

In the case of certain mixtures as with sulphuric acid and water the conductivity reaches a maximum value and then decreases. In the system sulphuric acid-water the maximum conductivity point is located at about 30 percent H_2SO_4.

Conductivity measurements have been made use of, to a very large extent in the theoretical study of solutions, in the testing of water, in the examination of soils, etc. It is evident that the last named case is closely analagous to the conditions under which clays are to be studied. Considerable work has been done by the Bureau



of Soils, U. S. Department of Agriculture, along these lines. A detailed description of the methods involved is given in Bulletin No. 61, by Davis and Bryan of the above Bureau entitled: "The Electrical Bridge for the Determination of the Soluble Salts in Soils."

The apparatus used for the determination of the conductivity of solutions is based on the principle of the Wheatstone bridge, which is shown in Fig. 1.[1] In this diagram R is a resistance box, S a cell with platinum electrodes between which is the solution,

[1] From G. Senter, *Outlines of Physical Chemistry*, p. 255.

the resistance of which is to be measured, *al* is a resistance wire stretched along a graduated scale, *c* is a sliding contact. By means of a battery which is not shown in the diagram, a direct current is sent through a coil, *K*, which gives an alternating current. This is divided into two branches, at *a*, reaching *b* by the paths *a d b* and *a c d* respectively. A telephone *T* is inserted which is silent when the points *c* and *d* are at the same potential. The contact *c* is shifted along the wire till the telephone no longer sounds. When this is the case the relation

$$\frac{\text{Length of } ac}{R} = \frac{\text{Length of } cb}{S}$$

holds. Since *a c*, *c b* and *R* are known, *S*, the resistance of the electrolyte column between the electrodes can at once be calculated.

Many forms of the electrical bridge are available for this work. In the present study a bridge kindly loaned us by the Bureau of Soils was used and later an instrument made by Hartmann and Braun, Frankfurt, Germany. The latter was found very convenient and accurate.

In the Bureau of Soils apparatus a very compact electrolyte cup is used, having a capacity of 50 cc. It is made of hard rubber with brass electrodes heavily nickeled. It is turned, with $1\frac{1}{2}$ inches inside diameter and $1\frac{7}{10}$ inches inside depth. Slots 1 inch wide are cut through and the brass electrodes set in. Connection is made with the instrument by slipping the cup between two upright brass springs which make contact with the outside of the electrodes and which are connected as one arm of the bridge. This cup is very convenient in working with clays and was used also in connection with the Hartmann and Braun instrument.

It is apparent that the conductivity of clays in the plastic and slip states is dependent upon the character of the salts as well as upon their concentration, upon the water content, the amount of organic material and the physical structure of the clay. In the Bureau of Soils bulletin mentioned it is stated that the resistance of a soil having the same salt content increases with an increase in the fineness of the soil texture, that where the salts are composed in part of carbonates the resistance is much greater than when other salts alone are present, and that organic matter increases the resistance for the same salt content. Considerable work was done in

the investigation mentioned above examining different soil types to which known amounts of sulphates, chlorides and carbonates were added. Very convenient tables are also given for the reduction of the resistance values to a uniform temperature of 60°F.

With clays the factor of adsorption enters into consideration, and for this as well as the reasons already given it is not to be expected that the conductivity relation can be expressed as a linear function.

In the present work conductivity determinations were made upon clays with varying water contents, from the moist to the slip state. The clays in the dried, ground condition were made up with distilled water to the desired consistency. The electrode cup was filled with the material and allowed to stand for twenty minutes when the conductivity was determined. At the same time the temperature was read from a thermometer inserted in the clay and a sample was taken for the moisture determination. The temperature correction was, of course, made for every determination. It is to be expected that at first with a low water content the resistance will be high and drop rapidly as the plastic state is reached. Upon the addition of more water a minimum point is reached, generally quite sharply defined, Figures 2, 3, 4 and 5. This point, invariably located to the right of the water content representing the most plastic condition corresponds of course to the maximum concentration of the solution and is not necessarily connected with the demarcation between the lower limit of the plastic and the beginning of the suspended state. Although the idea of correlating the consistency of the clay with the electrical conductivity is very tempting it offers no hope of producing useful data. The question is governed by the amount of salts present in the dissolved and undissolved state and the amount of water available and depends also upon the state of equilibrium reached. The minimum point, however, may be used for comparing the relative salt contents of different clays. Thus the minimum resistance of the North Carolina kaolin is about 1530 ohms, of the Florida kaolin 1100 ohms, of the Georgia kaolin 280 ohms, of the Bedford shale 164 ohms. With a higher water content the conductivity becomes practically a linear function of the dilution. Any arbitrary water content may thus be used for purposes of comparison.

In estimating the content of soluble salts in a clay or clay body it is desirable to know at least their qualitative composition and dif-

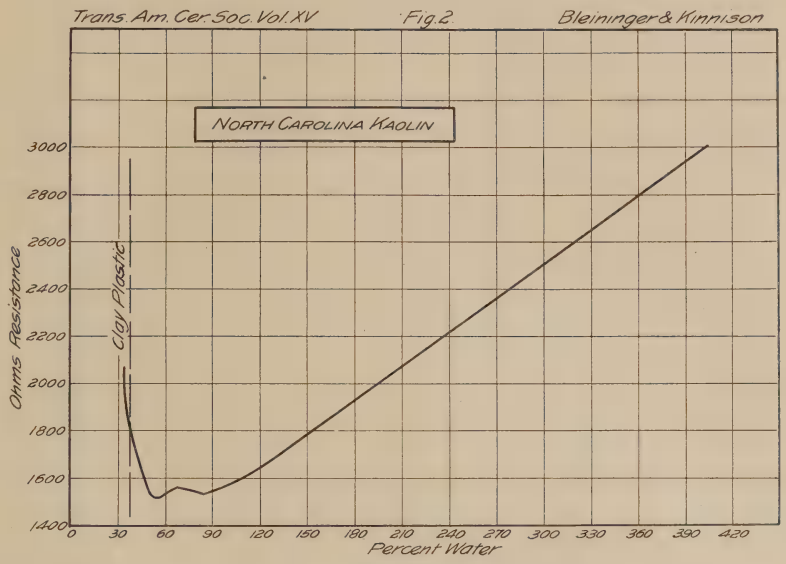
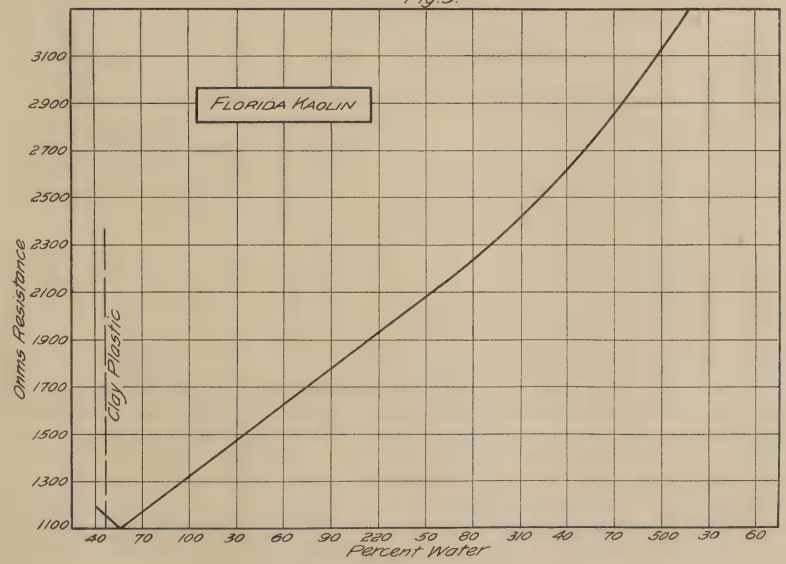

Trans. Am. Cer. Soc. Vol. XV
Fig. 2.
Bleininger & Kinnison
North Carolina Kaolin
Clay Plastic
Ohms Resistance
3000
2800
2600
2400
2200
2000
1800
1600
1400
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420
Percent Water

Fig. 3.


Florida Kaolin
Clay Plastic
Ohms Resistance
3100
2900
2700
2500
2300
2100
1900
1700
1500
1300
1100
40 70 100 30 60 90 220 50 80 310 40 70 500 30 60
Percent Water

ferent clays should not be compared indiscriminately without such knowledge. The case is quite simple where substances like sodium carbonate and sodium silicate are added to slips since by using known amounts of the mixture a table may readily be prepared correlating the electrical resistance with the percentage of the reagents.

In order to show the relation between the total amounts of soluble salts in five clays of the impure type and the electrical conductivity the following determinations were made. Ten grams of the dried clay was weighed out and placed in a small ball mill with 500 cc. of distilled water, together with about a dozen small pebbles carefully washed in pure water. After running the mill for three hours the liquid was transferred to a stoppered bottle and allowed to stand for some days. The suspended matter was caused to precipitate by the addition of ammonium chloride (solid). A portion of the practically clear solution, 200 cc., was then removed, a small amount of aluminum chloride added and precipitated by means of ammonium hydroxide. The liquid was then filtered through a dense filter, evaporated to dryness in a platinum dish, ignited and weighed. Before adding the ammonium chloride to the clay suspension the latter was well shaken and the electrical conductivity determined. The results obtained are as follows:

Clay	Percent soluble salts	Resistance in ohms. reduced to 60° F.
Surface clay, Cleveland, O.....	2.10	2110
Surface clay, Curtice, O.....	1.05	3160
No. 3 fire clay, Aultman, O.....	0.94	3790
Shale, Independence, O.....	0.60	3970
Shale, Canton, O.....	0.77	3650

From these figures it appears that there is a fair agreement between the conductivity and the amount of soluble salts in spite of the fact that the soluble matter differs widely in composition and in part consists of substances not dissociated and hence non-conductors.

In order to determine the effect of dissolved calcium sulphate upon a clay low in soluble salts the following experiment was carried out. A sample of North Carolina kaolin was thoroughly mixed and washed by decantation with distilled water until the conduc-

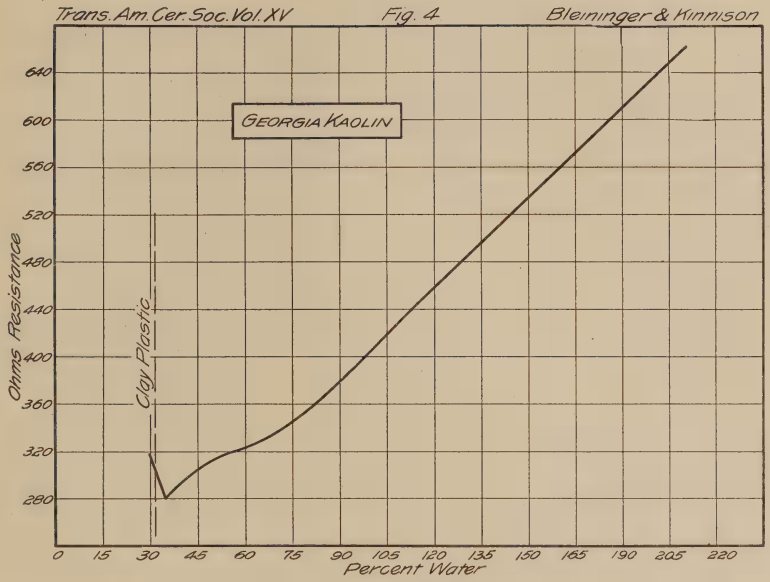
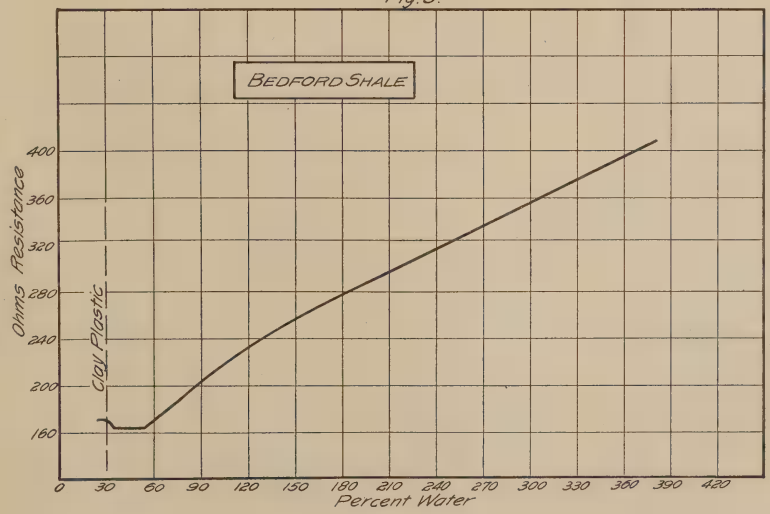
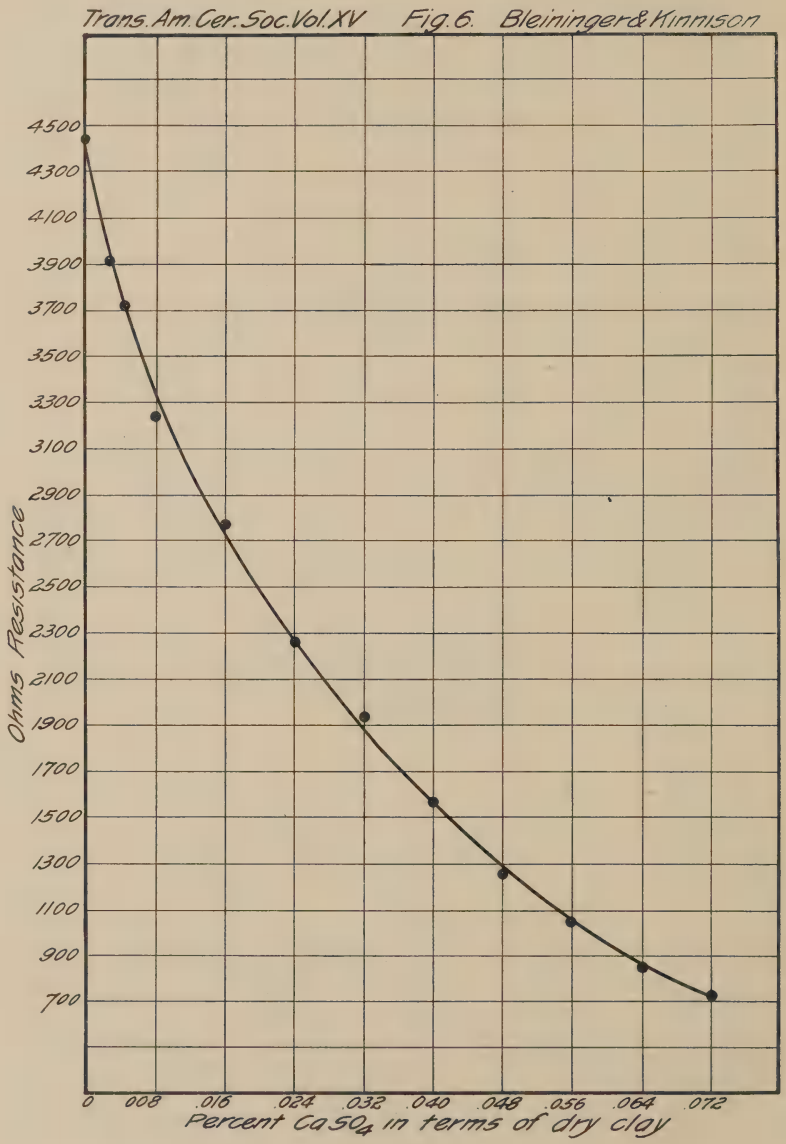

Trans. Am. Cer. Soc. Vol. XV
Fig. 4
Bleininger & Kinnison
GEORGIA KAOLIN
Clay Plastic
Ohms Resistance
640
600
560
520
480
440
400
360
320
280
0 15 30 45 60 75 90 105 120 135 150 165 190 205 220
Percent Water

Fig. 5.


BEDFORD SHALE
Clay Plastic
Ohms Resistance
400
360
320
280
240
200
160
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420
Percent Water


Trans. Am. Cer. Soc. Vol. XV Fig. 6. Bleininger & Kinnison
Ohms Resistance
4500
4300
4100
3900
3700
3500
3300
3100
2900
2700
2500
2300
2100
1900
1700
1500
1300
1100
900
700
0
.008
.016
.024
.032
.040
.048
.056
.064
.072
Percent $CaSO_4$ in terms of dry clay

tivity of the wash water was reduced to 30,000 reciprocal ohms, using the cup of the Bureau of Soils apparatus.

A saturated solution of calcium sulphate was then prepared by grinding some plaster of paris in distilled water in a ball mill, allowing to stand for several days, and filtering. To the prepared kaolin, requiring 36 percent of water to attain the state of soft consistency increasing amounts of the calcium sulphate solution were then added and the conductivity of the clay determined. The water content was maintained throughout at 36 percent. The results are represented in the diagram of Figure 6. The curve thus obtained shows that the conductivity is not directly proportional to the amount of sulphate added. The change takes place more rapidly with the first additions and more slowly with the last. It is noted that as small an amount as 0.072 per cent of dissolved calcium sulphate can bring about a decrease in the resistance of the plastic mass from 4440 to 720 ohms.

The determination of the electrical conductivity undoubtedly could find useful application in ceramic practice, especially in the control of casting and clay slips, boiler and tempering water, etc.

DISCUSSION

Mr. Purdy: May I ask if the accuracy of this method does not depend upon the salt? Isn't it more accurate with some salts than others?

Prof. Bleininger: With carbonates this relation is not the same as with other salts, but it has been worked out with reference to carbonates. All of these results must be corrected for temperature and we have used the tables of the Bureau of Soils. With material as heterogeneous as clay, it would be absurd to require the accuracy of a bridge as used for measuring the conductivity in physical-chemical work but I think the instrument is sufficiently accurate for our purpose.

Mr. Boar: I would like to ask if that method might not be used as a rapid means of determining the amount of water in plastic clay, instead of drying it out?

Prof. Bleininger: Possibly, but I am afraid it would not be quite accurate enough for this purpose since the amount of soluble salts varies.

TALC AS A BODY MATERIAL

BY C. W. PARMELEE AND G. H. BALDWIN

INTRODUCTION

There are a number of references to be found in ceramic literature to the use of steatite or talc[1] in body composition. In Dillon's book on *Porcelain*, page 131, mention is made of the possibility of the mineral having been used by the Chinese, although he says that is a disputed question. On page 359 we learn that a paste was used at Worcester about 1746 which contained one-third steatite, also that it entered into the composition of certain Chinese, Italian and Spanish wares.

Salvetat, on pages 11 and 12 of Vol. II of *Lecons de Ceramique* speaks of the use of this mineral.

Brogniart, in *Traites des Artes Ceramiques*, Vol. I, page 71, says that steatite is sometimes introduced in body mixtures in small quantities but is only rarely used. In the second volume, page 422, he describes its use in the manufacture of porcelain at Turin, Italy, 1807. In the body there described, steatite was 28 percent of the mixture while the clay content was only 9 percent. It gave a fine body having a slightly yellow color and a slight translucency. It resisted changes of temperature very well providing that they were not too sudden. Brogniart made some experiments on mixtures of a similar sort and obtained satisfactory results. The manufacture at Turin was finally abandoned. On page 424, the same writer describes porcelain containing steatite made in Spain about 1812, which was similar to that of Turin.

Hegeman in *Des Porzellans*, page 33, describes steatite as useful in the manufacture of bisque porcelain, lithophanie and craqule glazes.

The *Manual of Practical Pottery*, contains on page 14, a recipe for the preparation of "French Limoges China" which has a content of steatite of 6 percent.

Rohland in *Sprechsaal*, 1906, page 673, advocates the use of talc in porcelain because it possesses certain properties similar to those

[1] "Talc" is the material obtained from dealers in potter's supplies and may be prepared from either of the minerals talc or steatite since they are alike in composition.

common to clays. In *Sprechsaal*, 1910, page 307 he compares the absorbing power of clay and talc and finds them very similar.

Purdy, *Trans. Am. Ceramic Society*, Vol. VII, page 105, found the use of talc as a flux for floor tile was undesirable.

Dana in *Manual of Geology*, 12th ed., page 327, says that "soapstone is used in the manufacture of porcelain; it makes the biscuit semi-transparent, but brittle and apt to break with slight changes of heat."

Summing up the above, we are lead to the conclusion that talc or steatite has long been recognized as a material available for use in the preparation of ceramic bodies to which it imparts useful properties.

EXPERIMENTAL WORK

The bodies selected for the purpose of experiment were of the following composition.

MIXTURE	A	B	C	D	E
Clay	50	47.5	42.5	37.5	32.5
Flint	45	42.5	37.5	32.5	27.5
Feldspar	5	10.0	20.0	30.0	40.0

The clay content was composed of:

	percent
Hammill and Gillespie's A, 1, china clay	25
English china clay No. 7	25
Crossley's English ball clay	25
Hammill and Gillespie's ball clay	25

The talc, purchased from a dealer in potters' supplies, was introduced into each of the above series in the proportions given in Table 1. In arranging the proportions of these mixtures, it was necessary to make an allowance for the silica of the talc composition which is about two-thirds[2] of the mineral. Consequently a suitable reduction in the silica was made with the increasing amounts of talc.

These mixtures were weighed out separately in batches of 1800 grams each, blunged, put through 100-mesh lawn, poured out in

[2] Talc has a composition: Silica, 62.8 percent; magnesia, 33.5 percent; water, 3.7 percent.

TABLE I.—COMPOSITIONS USED.

		CLAY	FELDSPAR	FLINT	TALC
		percent	*percent*	*percent*	*percent*
A	0	50.0	5	45.0	0
	1	50.0	5	44.3	1
	2	50.0	5	43.6	2
	3	50.0	5	43.0	3
	4	50.0	5	42.3	4
	5	50.0	5	41.6	5
	6	50.0	5	40.3	7
	7	50.0	5	38.3	10
	8	50.0	5	37.0	12
	9	50.0	5	35.0	15
	10	50.0	5	33.0	18
	11	50.0	5	31.6	20
	12	50.0	5	28.3	25
	13	50.0	5	25.0	30
B	0	47.5	10	42.5	0
	1	47.5	10	41.9	1
	2	47.5	10	41.2	2
	3	47.5	10	40.5	3
	4	47.5	10	39.9	4
	5	47.5	10	39.2	5
	6	47.5	10	38.0	7
	7	47.5	10	35.9	10
	8	47.5	10	34.5	12
	9	47.5	10	32.5	15
	10	47.5	10	30.5	18
	11	47.5	10	29.2	20
	12	47.5	10	26.0	25
	13	47.5	10	22.5	30
C	0	42.5	20	37.5	0
	1	42.5	20	36.9	1
	2	42.5	20	36.2	2
	3	42.5	20	35.5	3
	4	42.5	20	34.9	4
	5	42.5	20	34.2	5
	6	42.5	20	33.0	7
	7	42.5	20	30.9	10
	8	42.5	20	29.5	12
	9	42.5	20	27.5	15
	10	42.5	20	25.5	18
	11	42.5	20	24.2	20
	12	42.5	20	21.0	25
	13	42.5	20	17.5	30

TABLE I.—Continued.

		CLAY	FELDSPAR	FLINT	TALC
		percent	*percent*	*percent*	*percent*
D	0	37.5	30	32.5	0
	1	37.5	30	31.9	1
	2	37.5	30	31.1	2
	3	37.5	30	30.5	3
	4	37.5	30	29.9	4
	5	37.5	30	29.2	5
	6	37.5	30	27.9	7
	7	37.5	30	25.9	10
	8	37.5	30	24.5	12
	9	37.5	30	22.5	15
	10	37.5	30	20.5	18
	11	37.5	30	19.2	20
	12	37.5	30	16.0	25
	13	37.5	30	12.5	30
E	0	32.5	40	27.5	0
	1	32.5	40	26.9	1
	2	32.5	40	26.1	2
	3	32.5	40	25.5	3
	4	32.5	40	24.8	4
	5	32.5	40	24.2	5
	6	32.5	40	22.9	7
	7	32.5	40	20.9	10
	8	32.5	40	19.5	12
	9	32.5	40	17.5	15
	10	32.5	40	15.5	18
	11	32.5	40	14.2	20
	12	32.5	40	11.0	25
	13	32.5	40	7.5	30

layers of uniform thickness on cloth covered plaster slabs. When sufficient water had been absorbed to leave the bodies in a workable condition, they were rolled up in the cloths and stored in a damp place so that each mixture aged for at least a week. Upon the expiration of that period, the bodies were jiggered to form cups having, after burning, a height of about 4.5 cm. ($1\frac{9}{16}$ inches) and diameter of 7.5 cm. (3 inches, approximately) and a thickness of 5 to 6 mm. All the mixtures proved to be easily workable, strong and generally dried safely.

Besides making the cups, we prepared, by casting in plastic molds, discs each having diameter of 3.8 cm. ($1\frac{1}{2}$ inches) and a thickness of 1.25 cm. ($\frac{1}{2}$ inch). These were intended for the determinations of shrinkage and porosity. Further we made wedge shaped pieces from the plastic body 4.6 cm. ($1\frac{13}{16}$ inches) long, 1.8 cm. ($\frac{1}{2}$ inch) wide and tapering from 1.1 cm. ($\frac{7}{16}$ inch) to 0.5 cm. ($\frac{3}{16}$ inch). These were intended for translucency tests.

The cups were set in saggars in pairs inverted rim to rim. The other pieces were also placed in saggars. The burning was done in our coal fired laboratory kiln at cones 6, 8 and 11. Duration of the burns was twenty to twenty-two hours.

RESULTS OF CONE 6 BURN

Color. Generally the addition of increasing amounts of talc gives a white color. A considerable variation was noted, for example, numbers 8 to 13 of the D series are quite yellowish, while D–1 to 7 are the whitest of the whole lot. This seems to be due to a slight variation in the temperature, for the cones set in each saggar indicated a maximum variation of one cone. Further, the yellowish trails were less translucent.

Deformation. None of these trials were deformed although the following showed more or less strong markings of the stilts upon which they rested indicating a beginning of the softening. B series, 8 to 13 inclusive; C series, 8 to 13; D series, 6 to 13; E series 8 to 13.

Translucency, Method. Attempts made to use the wedge shaped pieces by interposing a grating[3] between them and 16 c.p. electric light failed to give satisfaction. We accordingly placed the lamp bulb within and immediately below a slot cut in the top of a wooden box and, after calipering the cups to determine the uniformity of thickness of wall, placed the side of the cup on the slot over the lamp. This method was inadequate in that it afforded no means for closely comparing translucency values, but it enabled us to determine at what point in the scale of mixtures translucency began and whether translucency increased or diminished with varying compositions. As a further refinement we interposed a fine wire between the light and the trial piece. With pieces of

[3] *Trans. Am. Cer. Soc.*, XIII, p. 104.

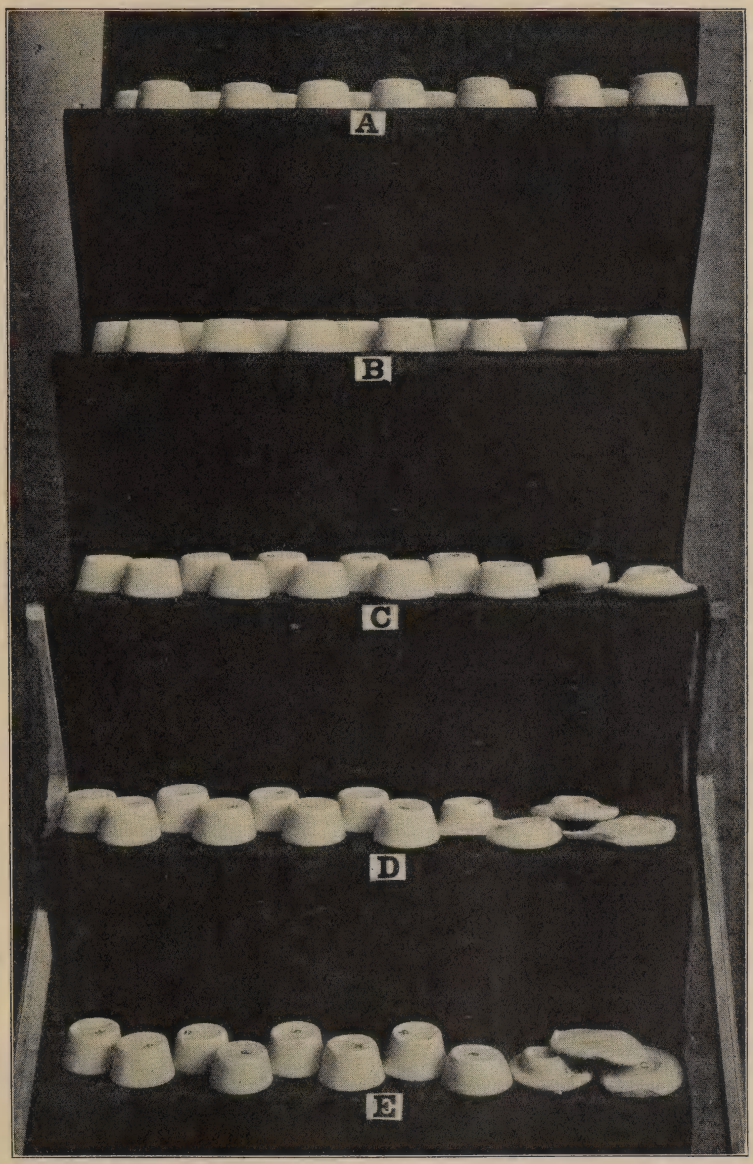


Plate 1

slight translucency, this could not be detected unless it was moved across the illuminated field. It could be seen while in a stationary position with pieces of a higher translucency. Efforts to give this more definite expression by varying the guage of the wire, i.e., by substituting wire of larger diameter for the smaller were fruitless. The shadow of the fine wire was as readily seen as that of the coarser.

Results.

A series. None showed translucency.

B series. 7 to 13 were increasingly translucent but not strongly so.

C series. 5 faintly translucent, which increases slightly.

D series. 1 much more, other numbers to 7 inclusive increasingly, 8 to 13 only faintly translucent.

E series. 0 faintly, 1 much more so.

RESULTS OF CONE 8 BURN

Color. The color of the biscuit becomes whiter or grayer as the amount of talc increases.

Surface. Series C-6 to 13; D-7 to 13; E-5 to 13 show slight blistering.

Deformation. Series A and B do not show deformation, but a softening of the pieces of higher content of talc is indicated by marks on the pieces made by the bitstone upon which they were set. Series C, 9 shows a tendency to squat down which is very marked in 10, 11, 12 and 13. Series D, 8 to 13 are badly deformed. Series E, deformation begins in 5 and the remaining numbers are badly deformed.

Translucency.

A series. Translucency increases from faint appearance in 8.

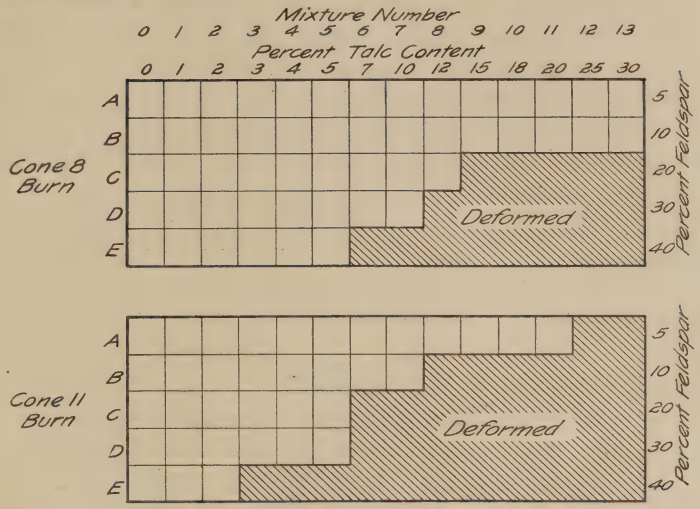
B series. Translucency begins faintly in 4.

C series. Translucency begins faintly in 1.

D series. Number 0 is tranlucent.

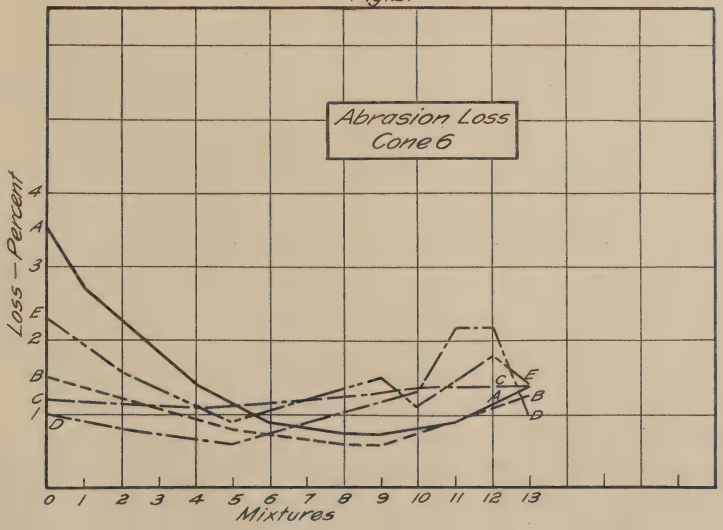
The following numbers have about the same translucency: A-10, B2-7; C-2; D-0. E-0, is very much more translucent than the preceding.

Trans. Am. Cer. Soc. Vol. XV Fig. 1. Parmelee & Baldwin



Charts showing areas of deformation at the two cone temperatures.

Fig. 2.



RESULTS OF CONE 11 BURN

Those which deformed badly at cone 8 were omitted.

Color. An increase of talc, even of 1 percent, produces a whiter or grayish color.

Surface. Small blisters occur in Series A-11 to 13; Series B-9 to 13; Series C-7 to 13; Series D none; Series E none.

Deformation. Deformation began in Series A with 12; in Series B, with 8; in Series C, with 6; in Series D, with 6; in Series E, with 3 slightly. The deformation increased rapidly in each instance.

Translucency. Translucency was faint with series A-8. Series B-0. C-0 was quite translucent. D-14 was very translucent. Translucency increased in every case with increasing percentage of talc.

Selecting a few of these for comparison:

A-9 and B-1 have about the same translucency.

A-12 and C-0 have about the same translucency.

A-11 and D-0 have about the same translucency.

Comparison of Samples from the Three Burns. Comparing various samples for translucency as affected by the temperature of burning we have:

CONE 6	CONE 8	CONE 11	
A–0	A–10	A–8	have about equal translucency
B–7	B–5	B–0	have about equal translucency
C–6	C–3	C–0	have about equal translucency
D–7	D–7	D–0	have about equal translucency
	E–13 is	not equal to	to E–14 at cone 11

It was noticed that in all cases trials containing talc gave whiter transmitted light than those without.

ABRASION AND COOLING TESTS

Abrasion Test. The cast pieces, one of each mixture, previously mentioned, from the burns at cone 8 and cone 11 were placed together in a small porcelain jar (one gallon capacity) of a ball mill and "tumbled" for ten hours. The results obtained by calculating the percentage losses on each piece were plotted. There were some wide variations naturally, but smoothing out the irregu-

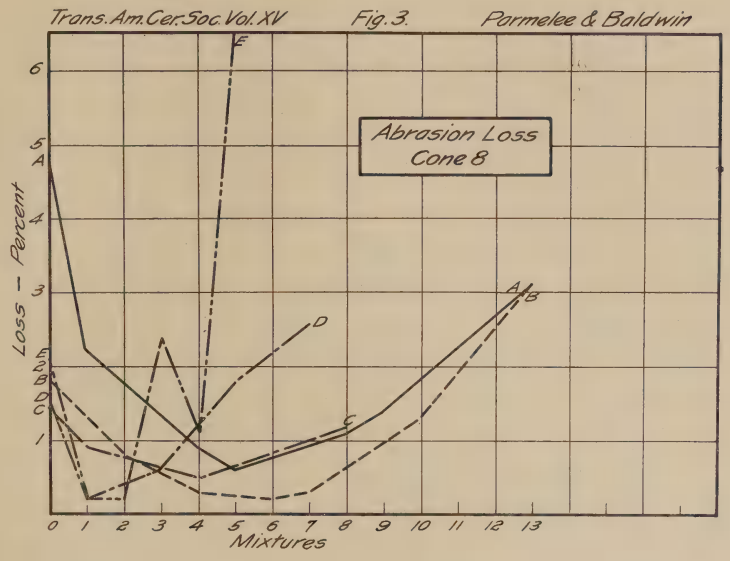
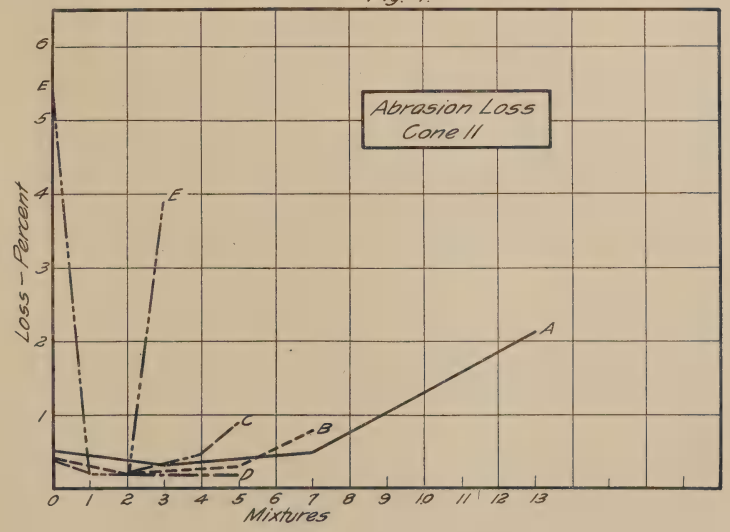

Trans. Am. Cer. Soc. Vol. XV
Fig. 3.
Parmelee & Baldwin
Abrasion Loss
Cone 8
Loss - Percent
Mixtures
A
B
C
D
E

Fig. 4.


Abrasion Loss
Cone 11
Loss - Percent
Mixtures
A
B
C
D
E

larities, we have the curves shown in Figs. 2, 3 and 4, which are worth considering.

Cooling Test. The results obtained were very unsatisfactory and served only to show that the method was inadequate. As a basis of comparison we purchased several small red-ware cups with a white lining, which are used in households for baking. They apparently were of two different makes, since one lot was stamped with the makers trade mark while the other had no distinguishing mark. These were heated in an oven to a temperature 140°C. and then plunged into water at a temperature of 10°C. without damage even to the glaze. The test was repeated several times with the same results. Some of the above series were tested in the same way without any effect that could be noticed. This test was abandoned and a Seger kiln was heated to 470°C., as indicated by a pyrometer, a red-ware cup was placed in the crucible of the furnace; and when the pyrometer indicated the above temperature, the cup was withdrawn and quickly plunged into ice water. This was repeated ten times. Three of each make were tested in this way. One of each make broke in this test. Our trial pieces burned at cones 8 and 11 were subjected to the same test with only an occasional broken piece. Some of the bodies spalled badly, which was due to water being taken into the pores and there suddenly being turned into steam.

This test proving inadequate, a measured quantity of water was placed in both red-ware pieces, and some of our trials, and small pieces of C. P. tin, melting point 232°C., were placed in the cups to serve as pyrometers. The water boiled away and the tin melted but no harm was done to the cups. While still hot, these were immersed in cold water but without apparent effect. To increase the severity of the test, it was repeated using small pieces of zinc, melting point 419°C., and upon the appearance of melting of the zinc, the cups were dipped into water but without any breaking. We are now seeking a test which will be adequate for the purpose.

It was noticed in case of both the red-ware and our trials that the heating in the Seger furnace and sudden cooling destroyed the "ring" of the pieces, excepting those trials high in clay.

SUMMARY

Talc as a body material may be introduced in considerable quantities at the expense of the clay content without affecting the working properties of the body.

It has a decided influence towards promoting the translucency of the ware even when introduced in small quantities. The light transmitted through such translucent ware is of a whiter quality.

The color of the ware is made whiter by the addition of the talc, and becomes of a grayish tone in some mixtures.

Talc promotes vitrification in the body. This vitrification proceeds slowly and apparently without the sudden fusion peculiar to lime.

Progressive additions of talc to a body, up to certain limits, increases the toughness as measured by abrasion loss. This increase is noticeable with all the feldspar contents examined. This is quite in accord with the statement by Richard (*Proceedings of Congress of Applied Chemistry*, 1909. *Abstracts Eng. Cer. Society*, Vol. VIII, page 13) that "the usual lime earthenware is comparatively easily breakable. The introduction of magnesia as well as lime into the clay body gives more resistive power toward knocks or pressure."

DISCUSSION

Mr. Bleininger: I think this paper is a very valuable contribution to our knowledge of bodies. I would like to simply suggest something in regard to translucency. Translucency might be measured by means of a selenium material, which has the property of having its conductivity lowered as light falls upon it. In this manner, numerical data could be obtained. This method is used, as we know, in astronomy for measuring and comparing the various light intensities of stars.

Prof. Orton: I would like to ask Professor Parmelee if he has made any inquiry into the availability of steatities of this grade? Is it a practical thing to buy it on the market at prices we could afford to pay?

Prof. Parmelee: American talc is quoted at $15 to $20 per ton; the French at $15 to $25; and the Italian at $35 to $40. We have rather large steatite deposits in the state of New Jersey, and it seems to me that possibly there might be some useful application of material derived from such sources.

Mr. Barringer: I think I can answer Professor Orton's question by stating that a very good trade of American talc can be obtained on the market at from $15 to $20 per ton, that the French talc costs about 25 percent more, and that the Italian talc, which is considered the finest grade, brings $35 to $40 per ton. This shows that talc is commercially available as a body ingredient wherever its use is required or should it become of any considerable value in the ceramic industries. It is used extensively in the rubber and paint industries and that has thrown it on the market in large quantities.

I have enjoyed Professor Parmelee's paper. It seems to me that it has focused the attention of the Society upon a body constituent that promises to be of considerable value, as is evidenced by the fact that steatite, talc and soapstone have been used for a considerable time. For instance, at Chattanooga the so-called lava deposits are in reality magnesium silicate and probably of some steatite and talc formation. In Germany they make a very considerable amount of ware that they call steatit, which is undoubtedly a mixture of steatite and clay, and I have seen a number of those pieces which were exceedingly tough and heat resistant.

Professor Parmelee touched upon a number of points, including toughness, heat resistance, translucency, vitrification, etc., and it is to obtain all of these qualities, if possible, that steatite has been used. As you know, the gas tips, to use a similar illustration, are exceedingly heat resisting, and we have found in our own experience that the use of steatite or talc gives a heat-resisting body. At one time we used lava bushings to support the electrodes in arc lamps where the heat is not only intense at times, but changes abruptly, and finding that the lava was more or less expensive we resorted to a composition of our own and not only used talc, but we used all talc. That body is about 85 percent talc and 15 percent precipitated gelatinous magnesium silicate. The use of colloidal magnesium silicate gives the proper elasticity and flow, so that a body of this sort can be squirted into tubes.

These tubes become so hard and strong on drying that they may be formed into bushings of the desired shape by a screw machine operation. You can take those talc tubes, 4 or 5 feet long, and run them right through a screw machine operation the same

as you could a tube of metal, and such a process is of course very much cheaper than any process of moulding.

In another case, we used about 20 percent of talc along with Hammill and Gillespie's clay and obtained a body which is quite heat resistant but not vitrified. It was allowed to remain porous. Such a body finds particular use in electrical heating devices, where we require a composition which is not only heat-resistant but has insulating properties at high temperatures (red heat). Some one in this Society (I think Weimar and Dunn) showed very nicely the worthlessness of porcelain at temperatures of 300° C. for electrical insulation. When porcelain is as hot as 600 or 700°C. it is not an insulator, it is a conductor and is absolutely worthless. I bring this out to show an additional value that can be gained from using steatitic or talc bodies. These bushings of clay and talc mixtures will stand heating to redness and you can immediately plunge them into cold water without cracking. Porcelain under the same conditions flies into a thousand pieces. We have never made any investigation of the differences occasioned by varying the percentage of talc or steatite, but a body that contains talc is enormously more heat resistant than porcelain and enormously better as an electrical insulator.

Prof. Parmelee: About using steatite and colloidal magnesium silicate for pyrometer tubes—it certainly ought to stand all temperatures.

Mr. Barringer: That has also occurred to me; off hand I do not see any reason why it should not be used. I know the porcelain is very unsatisfactory. The German porcelain tubes are frequently broken and have to be replaced at considerable expense.

Prof. Orton: I would like to ask Mr. Barringer, isn't it true that the Chattanooga ware is turned from blocks of natural mineral?

Mr. Barringer: It may be made both ways. The natural stone cuts easier, with little or no wear on the tools. It was the practice to cut it just to the shape they want it and thread it and drill it and so on, but when the shapes become intricate, it becomes a matter of considerable expense, and while it is satisfactory for standard simple shapes, such as cylindrical pieces, it becomes decidedly expensive where the piece is irregular or where the piece is of considerable size even if it is of cylindrical shape. There are veins in the natural stone that prevent a great may parts from being perfect.

I have burned a block of the lava 8 or 9 inches square in the kiln and found a streak right across it that had fused; probably some iron bearing mineral, running right through the rock. Very often pieces must 4 or 5 inches in either direction and to run into one of those veins renders the piece worthless. In addition to that process, which they use, as I understand it, for all such small work as gas tips, they grind the material and press the dampened powder into the desired forms which are then dried and fired as with porcelain.

Prof. Orton: Do you know whether it requires high temperature in firing?

Mr. Barringer: I don't know what temperature they use. I think they add a little silicate of soda to the talc to give it some bonding qualities. I imagine they must fire it pretty high, although I know nothing definite about the firing process.

Mr. Watts: I would like to ask, at this point, whether anything has been done in the way of putting a glaze or a substitute for glaze, on any of this ware? You know where you have very much magnesium in a body, you get into difficulties in glazing. Did you do anything, Mr. Parmelee?

Prof. Parmelee: We have not been able to complete the glaze experiments.

Mr. Montgomery: I have been very much interested in this paper and in the discussion as I have had some experience along the same lines, although with porous bodies as just discussed by Mr. Bar ringer, rather than with vitrified bodies.

First, in regard to the test to which Professor Parmelee subjected his trials, I might suggest that he would have greater success in breaking them if he would use a change in temperature from the red heat to that of a cold air blast. In testing the resistance of gas mantle rings and pyrometer tubes to sudden changes of temperature, I have found this test to be much more intensive than cooling in water and much more satisfactory especially with porous bodies, which of course absorb some water.

I would also like to add to what Mr. Barringer has just said that my experince with the use of talc in porous bodies has been similar to his. I have developed a very satisfactory gas mantle ring body which is resistant to sudden temperature changes by the use of 15 to 20 percent of white talc in a wholly clay body.

STUDY OF SOME CALCAREOUS AND MAGNESIAN SLAGS[1]

A. FUSION STUDIES

BY A. V. BLEININGER, G. H. BROWN, AND C. S. KINNISON
PITTSBURGH, PA.

This paper is presented in two parts, one dealing with the melting of certain slags, by the authors, the other with the constitution of these materials, based upon microscopic examination, by Mr. A. A. Klein.

The work was undertaken for the purpose of studying calcareous and magnesian slags of the more acid type with reference to their possible utilization in the manufacture of building and paving bricks from clays and limestone or other calcareous materials in localities where no desirable shales or good building stone are available. The idea in mind was the production of such slag products not as a by-product in the manufacture of iron, but as an independent industry, endeavoring to use combinations of the raw materials available, which will result in slags readily poured and possessing the required physical properties. It would be necessary then to construct a furnace for the economical fusion of the slag, devices and machinery for molding the blocks and a suitable annealing kiln.

As a basis for the beginning of this study a knowledge of the melting range of clay and high calcium or magnesian limestone mixtures was necessary. It is obvious that deformation points offer the only criterion for the estimation of the fusion interval of such slags. The clay used as the starting point of the series was shale from Canton, Ohio. Two limestones were employed one of the high calcium, the other of the dolomitic type. The analyses of these three materials are as follows.

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[1] By permission of Director, Bureau of Standards.

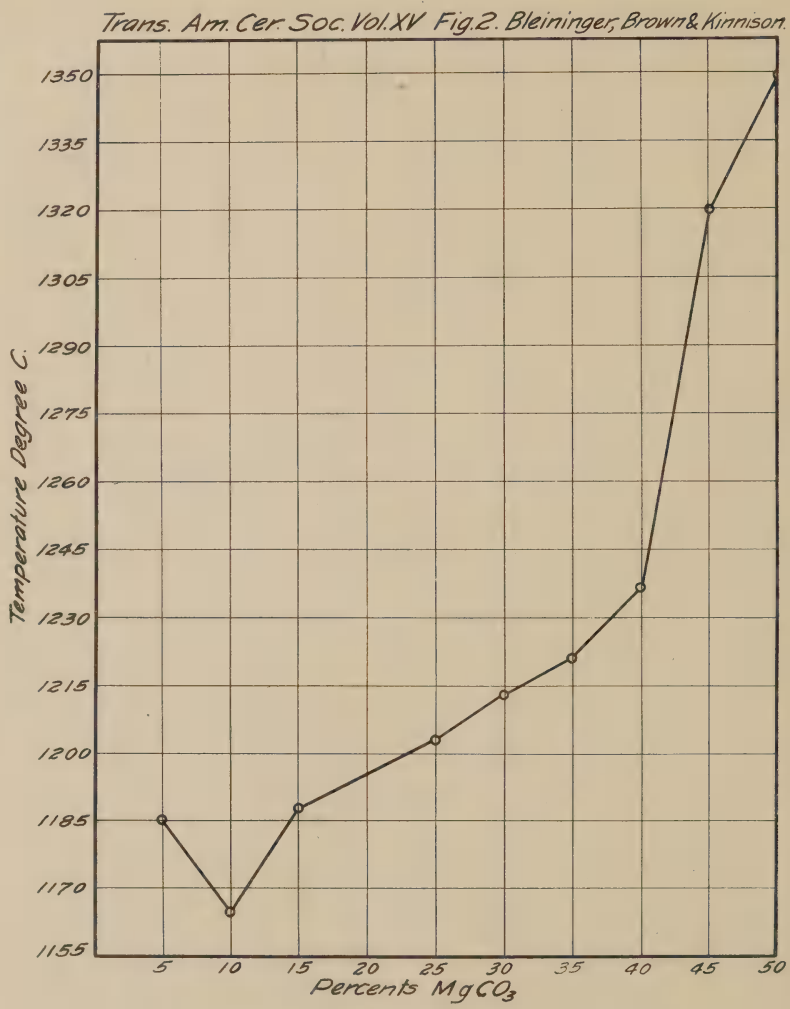
	SHALE	HIGH CALCIUM STONE	DOLOMITE
	percent	*percent*	*percent*
Silica	59.72	0.32	0.46
Alumina	19.28		0.23
Ferric oxide	7.99	0.08	0.13
Lime	1.21	55.40	30.28
Magnesia	1.77	0.76	21.74
Soda	0.47		
Potash	3.06		
Loss on ignition	6.96	43.79	47.44
Total	100.46	100.35	100.28

The preliminary work consisted in determining (*a*) the deformation points of shale—high calcium stone; (*b*) of shale—magnesium carbonate; (*c*) shale—dolomite mixtures, and (*d*) the effect of variations in silica, alumina, lime and iron oxide.

a. According to the customary practice cones were made up from the mixtures of the two materials, prepared by screening through the 40-mesh sieve. It was thought desirable to refrain from grinding the material too fine in order to approach more closely the conditions of practice. The cones were caused to go down in a large test kiln, the temperature being advanced at the rate of $16\frac{2}{3}$°C. per hour. The results are given in the diagram of Figure 1. From this curve it is evident that the deformation points do not show a regular sequence. This must be ascribed to the coarse grinding of the materials. The maximum between 28 and 34 percent of limestone is doubtful. The most easily fusing mixtures, about 34–36 percent of limestone show a softening temperature of approximately 1085°C. Beyond this point the fusion temperatures rise rapidly. In all subsequent work of this kind the materials were ground, dry, in the ball mill so that all of the powder passed the 100-mesh sieve.

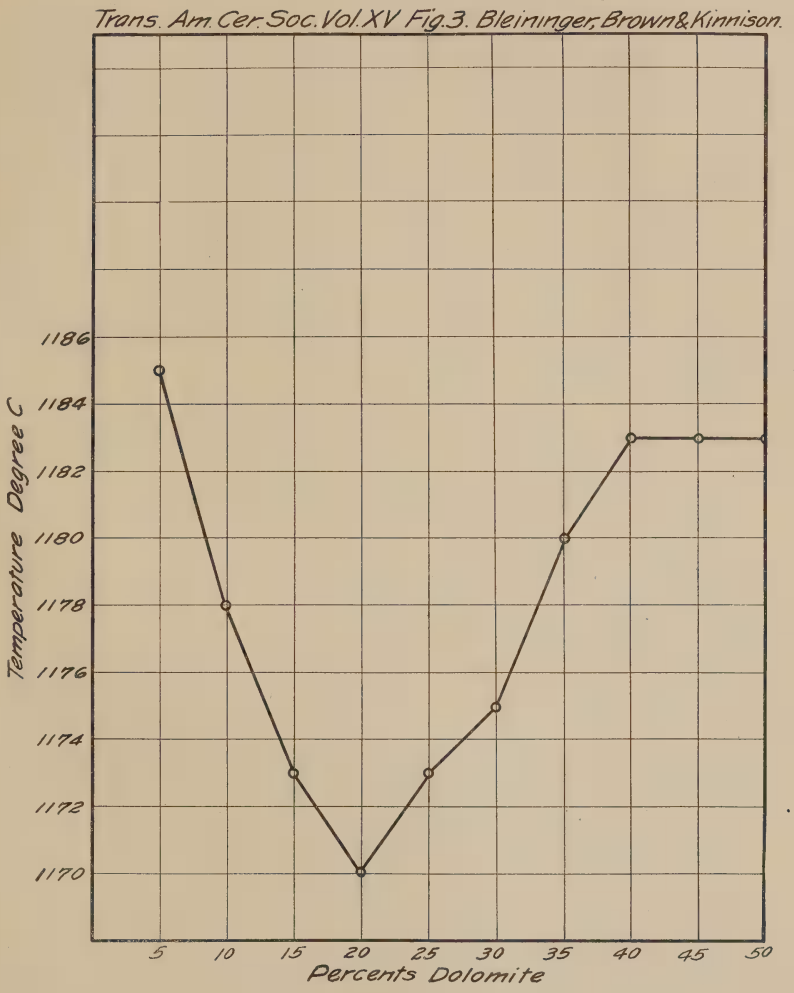
b. The deformation points of the finely ground shale-magnesium carbonate mixtures were obtained in a similar manner to those of the preceding series. The precipitated carbonate used was found to contain 88.77 percent of $MgCO_3$. From the diagram of Figure 2 it is noted that the eutectic mixture corresponds to 10 percent magnesium carbonate, with a deformation temperature of 1165°C.

Trans. Am. Cer. Soc. Vol. XV Fig. 1 Bleininger, Brown & Kinnison
Temperature Degree C.
1180
1170
1160
1150
1140
1130
1120
1110
1100
1090
1080
10 14 18 22 26 30 34 38 42 46 50 54 58
Percents Limestone



c. The deformation temperatures of the shale-dolomite series are given in Figure 3 where the eutectic mixture contains 20 percent of dolomite and the softening temperature is 1170°C.

d. For the purpose of determining the effect of variations in the silica-alumina and in the lime-ferric oxide ratios a series of compositions embracing 36 members was prepared from North Caro-



lina kaolin, flint, whiting and ferric oxide. In these slags the molecular silica-alumina ratios were varied as follows: 4 : 1, 5: 1, 6: 1, 7: 1, 8: 1, 9: 1. Expressed in terms, by weight, these ratios become 2.35: 1, 2.94: 1, 3.53: 1, 4.1: 1, 4.7: 1, 5.29: 1. The ratios by weight of calcium carbonate to ferric oxide were as follows: 3: 1, 4: 1, 5: 1, 6: 1, 7: 1, 8: 1. Each series of constant $SiO_2 : Al_2O_3$

ratio thus consisted of 6 members with varying proportions of $CaCO_3$: Fe_2O_3, the sum of which was kept constant at 36 percent.

Small cones were again made up from these mixtures and their deformation point noted in a platinum resistance furnace. The rate of heating employed was 20°C. per minute up to 900°, 10° from 900 to 1100°, and 5° from 1100° to the deformation point. It is to be expected that these values are higher than would be obtained in a large kiln with a lower rate of firing.

The compositions of the slags, based on the chemical analysis of the materials, made during the progress of the work and expressed in empirical formulae together with the softening temperatures are compiled in Table I.

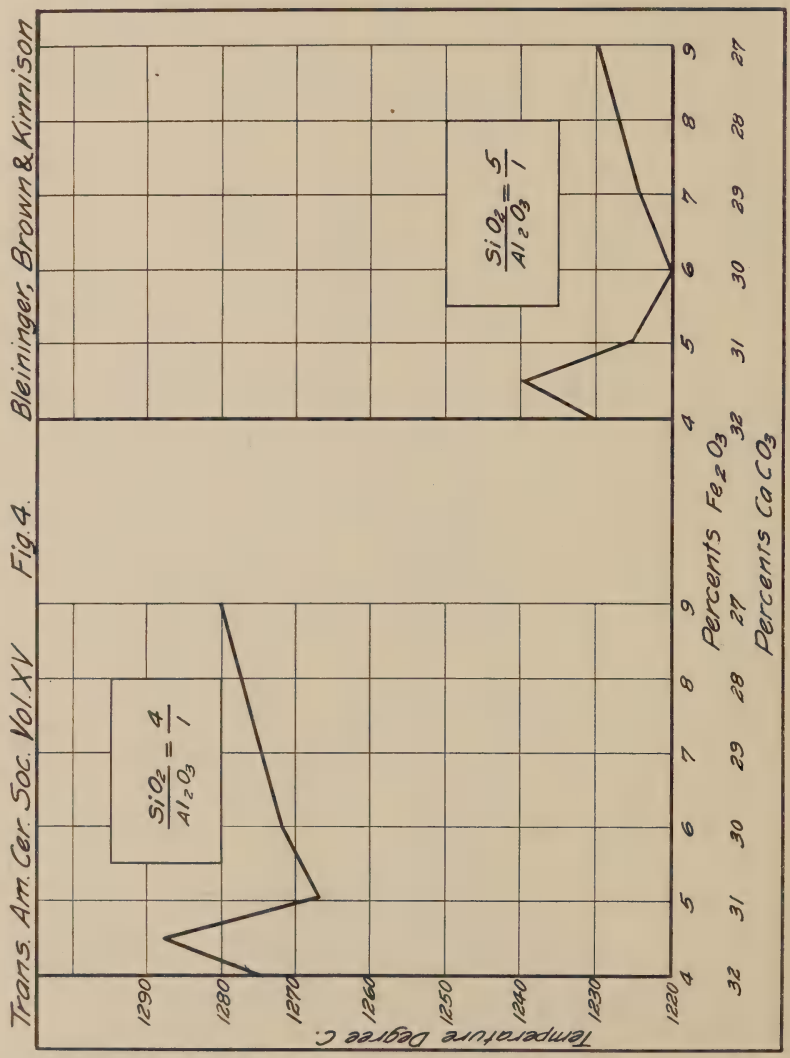
These results are shown graphically in Figures 4, 5 and 6. From these it appears that decrease in alumina results in increased fusibility, the lowest deformation temperature, 1160°, is reached with a molecular silica-alumina ratio of 7:1. Further reductions in alumina do not seem to bring about any decided changes. It is to be expected that with still smaller amounts of Al_2O_3 the softening temperatures will tend to become higher. As to the $CaCO_3$: Fe_2O_3 ratios of the lowest melting member of each series it is noted that the ratio becomes smaller as the acidity increases. More iron oxide thus enters into the eutectic mixtures as the proportion of silica becomes larger. While for the $4SiO_2$ 1 Al_2O_3 series the ratio of $CaCO_3$: Fe_2O_3 is 31:5, corresponding to a calcium carbonate content of 6.2 times the amount of ferric oxide it becomes 29:7 = 4.14 with 7 SiO_2 and 4.07 with 9 SiO_2. This relation is interesting as it applies also to iron carrying, calcareous clays in general. Slag No. 20, also was of interest owing to the fact that its fusion appeared to take place very suddenly and accompanied by decided fluidity.

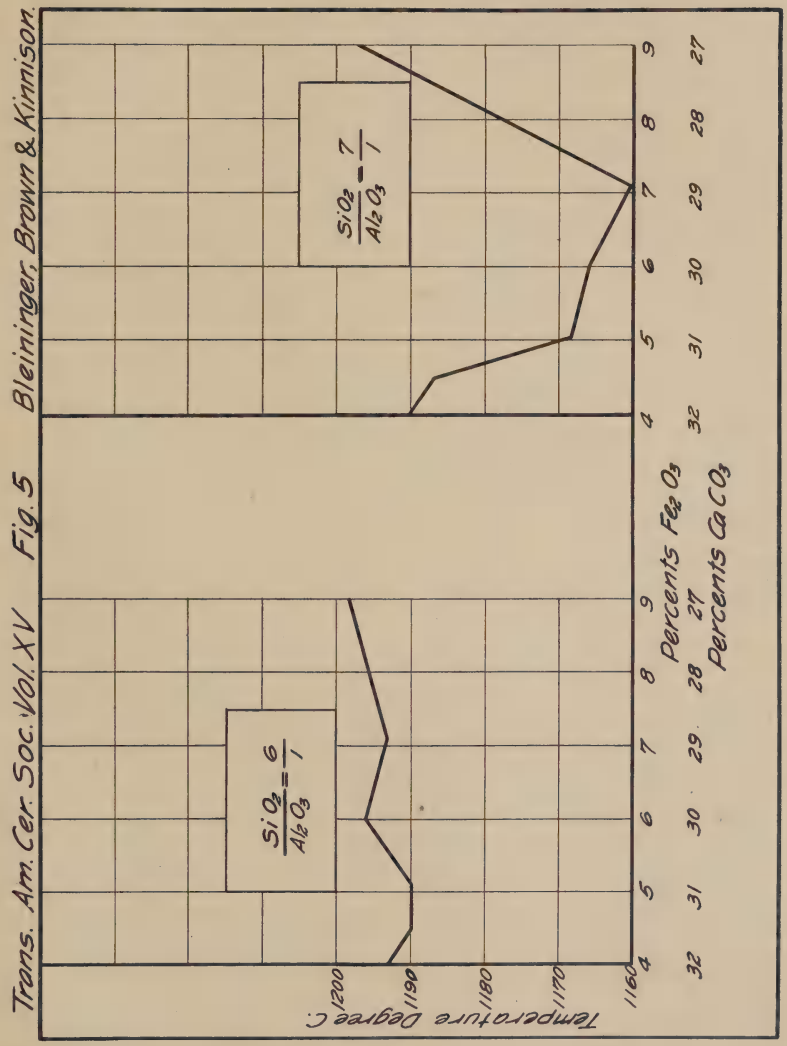
A knowledge of the most easily fusing slags by no means solves the problem at hand. It is just as essential if not more so to know the fluidity of the various slags at the available furnace temperatures and their tendency to produce a stony or crystalline structure. This part of the work was attacked by melting batches of the different slags and pouring them in iron molds. Mixtures of the shale and limestone or dolomite were prepared by grinding in a ball mill to pass the 80-mesh sieve. These were fused in

TABLE I

SERIES	NO.	CaO	K_2O	MgO	Al_2O_3	Fe_2O_3	SiO_2	SOFTENING TEMPERATURE
								deg. C.
A	1	0.982	0.007	0.011	0.589	0.215	2.51	1280
	2	0.983	0.007	0.010	0.555	0.176	2.36	1275
	3	0.983	0.007	0.010	0.531	0.131	2.26	1272
	4	0.984	0.006	0.010	0.518	0.112	2.20	1267
	5	0.984	0.006	0.010	0.508	0.096	2.16	1288
	6	0.984	0.006	0.010	0.500	0.085	2.13	1275
B	7	0.983	0.007	0.010	0.512	0.216	2.71	1230
	8	0.984	0.006	0.009	0.483	0.176	2.56	1225
	9	0.985	0.006	0.009	0.461	0.129	2.44	1220
	10	0.984	0.006	0.009	0.449	0.111	2.37	1225
	11	0.984	0.006	0.010	0.439	0.096	2.32	1240
	12	0.985	0.006	0.010	0.433	0.085	2.29	1230
C	13	0.985	0.006	0.008	0.451	0.214	2.86	1198
	14	0.986	0.005	0.008	0.422	0.175	2.68	1192
	15	0.986	0.005	0.008	0.406	0.131	2.58	1196
	16	0.986	0.005	0.008	0.395	0.110	2.51	1190
	17	0.986	0.005	0.009	0.387	0.095	2.48	1190
	18	0.986	0.005	0.009	0.381	0.086	2.42	1193
D	19	0.986	0.005	0.008	0.404	0.213	2.98	1197
	20	0.987	0.005	0.008	0.379	0.176	2.79	1160
	21	0.988	0.005	0.007	0.364	0.131	2.69	1166
	22	0.988	0.005	0.007	0.355	0.111	2.62	1168
	23	0.988	0.005	0.007	0.347	0.095	2.56	1187
	24	0.988	0.005	0.007	0.342	0.084	2.52	1190
E	25	0.987	0.005	0.008	0.367	0.214	3.08	1185
	26	0.988	0.005	0.007	0.344	0.174	2.89	1170
	27	0.988	0.005	0.007	0.330	0.180	2.77	1180
	28	0.988	0.005	0.007	0.322	0.110	2.70	1185
	29	0.988	0.005	0.007	0.316	0.095	2.65	1195
	30	0.988	0.005	0.007	0.311	0.085	2.61	1198
F	31	0.988	0.004	0.008	0.335	0.214	3.16	1180
	32	0.988	0.004	0.008	0.315	0.173	2.97	1168
	33	0.988	0.004	0.008	0.301	0.130	2.84	1180
	34	0.989	0.004	0.007	0.294	0.109	2.77	1185
	35	0.989	0.004	0.007	0.288	0.095	2.71	1197
	36	0.989	0.004	0.007	0.284	0.083	2.68	1195

large Battersea crucibles, size L, and poured in iron, two part gang molds, forming cylindrical pieces having a volume of 2 cubic inches. The molds were previously heated to redness and after


Trans. Am. Cer. Soc. Vol. XV
Fig. 4.
Bleininger, Brown & Kinnison
Temperature Degree C.
1290
1280
1270
1260
1250
1240
1230
1220
$SiO_2 = \frac{4}{Al_2O_3} \frac{1}{1}$
$SiO_2 = \frac{5}{Al_2O_3} \frac{1}{1}$
Percents Fe_2O_3
32 31 30 29 28 27 4 5 6 7 8 9
Percents $CaCO_3$
4 5 6 7 8 9 32 31 30 29 28 27


Trans. Am. Cer. Soc. Vol. XV Fig. 5 Bleininger, Brown & Kinnison.
Temperature Degree C.
1200
1190
1180
1170
1160
$\frac{SiO_2}{Al_2O_3} = \frac{6}{1}$
$\frac{SiO_2}{Al_2O_3} = \frac{7}{1}$
Percents Fe_2O_3
Percents $CaCO_3$
4 5 6 7 8 9
32 31 30 29 28 27

pouring covered with red hot sand to insure slow cooling. The composition ranged from 36 percent to 64 percent limestone and dolomite respectively. The effect of annealing was studied by heating the cooled slag cylinders in a large test kiln to the desired temperatures for two hours. The results of this work are given in the following paragraphs.

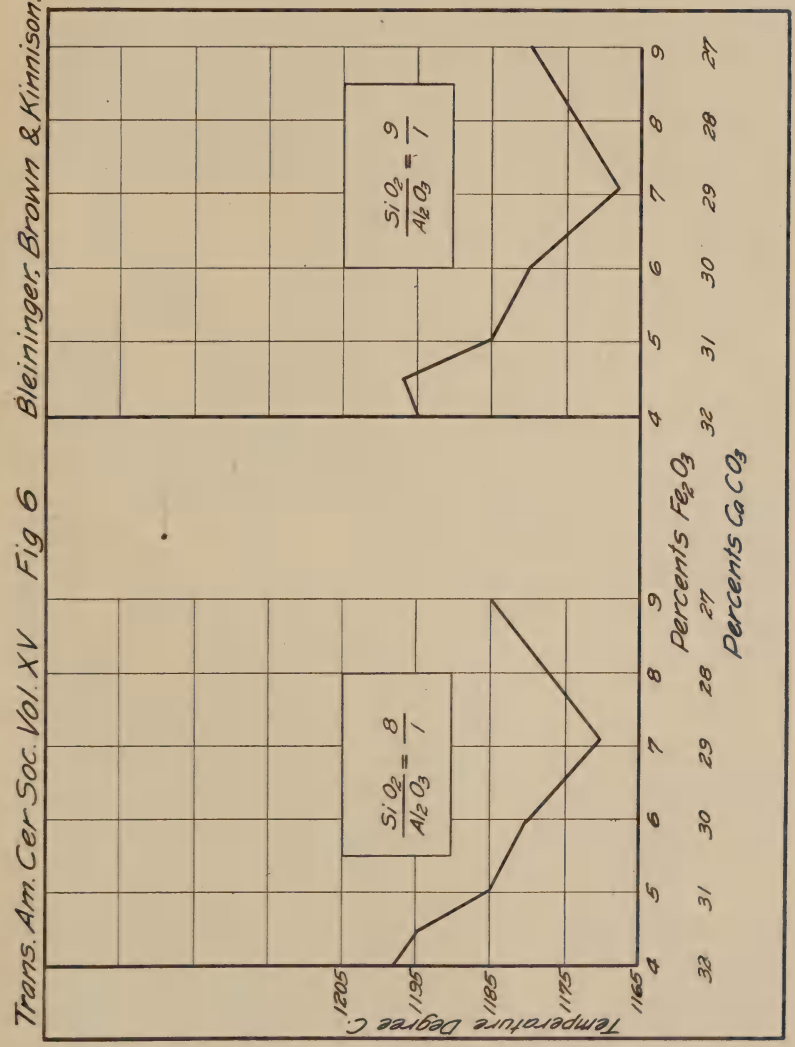
Number 1, 36 percent limestone, 64 percent shale. The furnace temperature was raised to 1300° and held there for twenty minutes when the slag was poured into the heated molds. The slag was black and glassy and the pieces free from bubbles. The fluidity was sufficient to fill the molds well but not as satisfactory as might be desired. In annealing at 900°C. the slag showed decided softening and deformation. A few scattered crystals were observed, but the glassy structure was retained. The same results were obtained at 850° and 800°. It was not found safe to heat the material above 800° owing to the deformation of the pieces.

Number 2, 40 percent limestone, 60 percent shale. A black glassy and somewhat brittle slag was obtained by pouring in the heated molds. No evidence of vesicular structure. The fluidity was about the same as for No. 1. Annealing at 850° and 800° brought about no crystallization. Deformation due to softening occurred at 850°.

Number 3, 44 percent limestone, 56 percent shale. Fused at 1300°. Slag black and glassy but showed a marked improvement in fluidity. The cylinders were brittle and broke readily upon removing from the mold. Upon annealing at 850° and 800° the glassy structure was retained.

Number 4, 48 percent limestone, 52 percent shale. Fused at 1300°, the slag showed excellent fluidity. It was black and glassy and very brittle upon removing from the molds. Annealing at 800° and 850° failed to produce a crystalline structure. Annealing was limited to 850° owing to softening as was the case with the other slags.

Number 5, 52 percent limestone, 48 percent shale. Fused at 1300°. Slag black, glassy and dense. Quite brittle on removing from molds. Pouring quality excellent. Annealing at 800° and 850° failed to produce crystalline structure. Some deformation at 850°.


Trans. Am. Cer. Soc. Vol. XV Fig 6 Bleininger, Brown & Kinnison.
Temperature Degree C.
1205
1195
1185
1175
1165
$\frac{SiO_2}{Al_2O_3} = \frac{8}{1}$
$\frac{SiO_2}{Al_2O_3} = \frac{9}{1}$
Percents Fe_2O_3
4 5 6 7 8 9
Percents $CaCO_3$
32 31 30 29 28 27

Number 6, 56 percent limestone, 44 percent shale. Fused at 1300°, and poured in hot molds as before. Fluidity excellent. The test pieces possessed a drab color and showed evidence of crystallization. A thin glassy coating was observed in the cylinders due to chilling in pouring. The brittle character of the slag was greatly reduced. Upon annealing at 800° and 850° the drab color changed to a reddish brown. The annealed pieces were very tough and homogeneous in structure. No deformation occurred at 850°.

Number 7, 60 percent limestone, 40 percent shale. Fused at 1330° but owing to segregation in the crucible, part of the batch formed a dense black glass and part a yellow tough body.

Number 8, 64 percent limestone, 36 percent shale. Fused at 1360°. The fluidity was satisfactory for pouring, but not quite as good as that of slags 3, 4 and 5. The specimens showed a gray, stony structure and great toughness and hardness. Crystallization was well developed. Glassy inclusions were scattered throughout the mass which did not disappear upon annealing at 800° and 850°. It is felt that the glassy material is due to solution of the crucible material and chilling in contact with the mold.

Number 9, 40 percent dolomite, 60 percent shale. Fused at 1300° and poured in heated mold. The cooled slag was dense, black, brittle and glassy. The fluidity was excellent. Annealing at 700°, 750°, 800°, 850° and 900° did not destroy the original glassy structure. No tendency to soften was observed at 850°.

Number 10, 44 percent dolomite, 56 percent shale. Fused at 1300°. Fluidity was excellent and superior to that of the lime slag of the same proportions. The slag was black, dense, but not uniformly glassy, the surfaces being opaque.

Upon annealing at 750°, 800° and 860° the original glassy structure was retained. At 900° a grayish green, crystalline structure, though not very pronounced, was obtained. This slag appears to be more resistant to deformation at the above temperatures than slag No. 3 of the limestone series.

Number 11, 48 percent dolomite, 52 percent shale. Fused at 1320°. Fluidity excellent. The slag was black, dense and partly glassy, partly opaque. Annealing at 900° produced a grayish green structure, very hard and tough, though crystallization was

not very pronounced. Lower temperatures of annealing brought about no change. No deformation noted at 900°.

Number 12, 52 percent dolomite, 48 percent shale. Fused at 1320°. Fluidity excellent. The slag was black, opaque, and possessed good toughness. Glassy structure no longer in evidence. Annealing at 750°, 800° and 860° brought about no change. At 900° a greenish yellow crystalline structure was developed, accompanied by good strength and toughness. Crystallization more pronounced than in Nos. 11 and 12. No deformation was observed at 900°.

TABLE II.

Number	4	5	6	7	8	9	10	11	12	13	15
Percent stone	48	52	56	60	64	40	44	48	52	56	64
Percent shale	52	48	44	40	36	60	56	52	48	44	36
Silica	42.36	39.76	37.09	35.37	36.52	46.49	45.13	42.94	40.56	38.14	36.67
Alumina	14.50	14.22	12.73	12.92	12.97	16.97	16.07	16.26	14.67	13.99	14.26
Ferric oxide	0.60	1.53	2.16	1.84	2.77	0.80	0.62	.....	2.51	2.97	0.75
Ferrous oxide	3.67	3.00	2.60	2.10	2.06	4.36	4.70	4.27	3.44	2.60	3.08
Lime	33.80	36.94	41.71	44.61	42.20	16.60	17.63	19.24	21.02	23.07	25.23
Magnesia	1.82	1.86	1.65	1.63	1.48	12.20	13.31	14.62	15.00	16.43	16.71
Soda	0.37	0.32	0.25	0.29	0.12	0.15	0.30	0.34	0.40	0.38	0.31
Potash	2.52	2.14	0.86	1.25	1.82	2.10	2.17	2.12	2.12	2.10	1.98
Loss on ignition	0.34	0.15	0.12	0.13	0.08	0.23	0.08	0.20	0.35	0.51	1.28

Number 13, 56 percent dolomite, 44 percent shale. Fused at 1320°. Slag black, dense, opaque, and showed good toughness. Fluidity very satisfactory. Annealed at 900° the slag is similar to No. 12. Good strength and toughness seemed to be possessed by the annealed slag.

Number 15, 64 percent dolomite, 36 percent shale. Fused at 1350°. Fluidity excellent. The slag was dark, dense, hard and showed a stony structure. Annealing at 900° produced a greenish gray structure and the slags had all the indications of good strength.

The slags obtained were analyzed, the results being compiled in Table II.

Samples of the slags were also taken, ground, and sieved through the 50-mesh screen, rejecting all material finer that 60-mesh. A uniform size of grain, corresponding to the range between the 50- and 60-mesh sieves was thus obtained. Two gram samples were then weighed out and boiled in a large excess of 10 percent acetic acid solution. The residues were then treated with a hot sodium carbonate solution, finally washed with hot water, ignited and weighed. The results obtained are given in Table III.

In the case of slag No. 7 two samples were prepared, one, marked 7, from the crystalline and 7c from the glassy portion. It is observed that the same slag in the crystalline state is decidedly more insoluble than when present as a glass. This, of course,

TABLE III

Number of slag	1	2	3	4	5	6
Insoluble residue, in percent	98.61	97.65	93.68	93.96	92.06	85.89
Number of slag	7	7c	8	9	10	11
Insoluble residue, in percent	98.69	92.38	90.08	97.54	96.57	96.52
Number of slag	12	13	14	15		
Insoluble residue, in percent	94.26	91.77	90.52	90.27		

agrees with theoretical considerations. The values thus obtained cannot, in the nature of the case, be expected to result in close correlation owing to variations in composition within the same batch and especially because of the differences in structure, which were referred to above. However, the evidence tends to show clearly that it is possible to produce slags quite resistant to the attacks of acids and hence to chemical, atmospheric influences.

It was thought desirable to determine the deformation temperatures of the fused slags by chipping off small fragments and causing them to go down in a platinum resistance furnace. That these temperatures can have no exact meaning is evident, since these slags show softening at temperatures as low as 800°. The fragments used were approximately of the same size and shape. The rate of heating was 20° per minute up to 900° and 2.5° per minute from this temperature to the temperature of total deformation.

The softening points thus determined hold only for this rate of heating and would be higher upon faster and lower with slow firing. The results are given in Table IV.

To complete this investigation there remains yet to be carried out the fusion of larger quantities of the most promising slags and the pouring of specimens of sufficient size for the determination of hardness and toughness. This requires additional apparatus now being supplied.

TABLE IV

NO. OF SLAG	PERCENT LIMESTONE	PERCENT SHALE	PERCENT DOLOMITE	DEFORMATION TEMPERATURE
				deg. C.
1	36	64		1180
2	40	60		1195
3	44	56		1195
4	48	52		1210
5	52	48		1235
6	56	44		1255
6A	58	42		1275
7	60	40		1270
8	64	36		1300
9		60	40	1225
10		56	44	1235
11		52	48	1240
12		48	52	1240
13		44	56	1240
14		40	60	1290
15		36	64	1295

In conclusion, it has been shown that suitable compositions should contain not less lime than is represented by that of slag No. 6, made up from 56 percent limestone and 44 percent of shale, or that corresponding to slag No. 12, composed of 52 percent dolomite and 48 percent shale. It has been shown that the limestone slags possess a far wider softening range than the dolomitic compositions and hence are more subject to deformation in annealing, though this difficulty disappears with the higher lime contents, 56 percent stone and above. The dolomitic slags as a class show greater fluidity, crystallize more readily and seem to be superior in hardness and toughness. These facts are of interest since

large quantities of magnesian limestone are available in different states and are not to be considered in connection with other uses such as the manufacture of Portland cement. It goes without saying that impure stones, rejected for lime making, are as useful for this industrial application as the purer material.

B. THE CONSTITUTION OF LIMESTONE-SHALE AND DOLOMITE-SHALE SLAGS

A. A. KLEIN, PITTSBURGH, PA.[2]

The subject of slags has interested the chemist, metallurgist and mineralogist for many years. It was through the study of these that many deductions were made concerning the crystallization of minerals in igneous rocks. Vogt[3] was among the first to attack this problem and worked in the beginning with artificial slags. Among the minerals noted by him were olivine, fayalite, monoclinic and rhombic pyroxenes, lime-feldspars, melilites, spinels, magnetite, apatite, etc. These compounds, with the exception of a few which are rare or unknown in nature, are the ordinary constituents of igneous rocks. Vogt found that quartz, the alkali feldspars, muscovite and hornblende do not occur in slags and there is good reason to believe they cannot be crystallized from a melt containing no water or other fluxes. Some of the investigators busied themselves with blast furnace slags, Bessemer slag, slags from zinc, lead and copper furnaces. Among those who worked on various phases of this (the silicate) problem are Akerman, Doelter, and the Geophysical Laboratory of Washington, etc.

The present investigation was carried out in connection with the development of an annealed slag brick. In this work naturally the technical features of the investigation were given more consideration than those relating to the theoretical side of the subject.

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[2] By permission of the Director, Bureau of Standards.

[3] Of Vogt's earlier works on slags the most important are "Studier over Slagger," *Bihangtil K. Svenska Vet. Akad. Handl.*, Vol. IX (1884); "Om Slaggers . . . ." *Jernkontorets Annaler* (1885); "Die Silikatschmelzlösungen, I, II, Vidensk-Selsk. Skrifter," *Math.-naturv.-Klasse.* (1903) No. 8, and (1904) No. 1. For a summary of the foregoing see "Die Theorie der Silikatschmelzlösungen," *Ber. des V. Intern. Kongr. Angew. Chemie zu Berlin* (1903), Sekt. III, A, vol. II, pp. 70–90.

Two series of slags were made, one consisting of a mixture of limestone and shale, the other containing dolomite and shale.

The method of preparation in brief was as follows. The mixture of the raw materials in the desired amounts was heated up to melting, poured into iron molds which were then banked with red hot sand to insure slow cooling. After cooling, part of the slags were placed in a furnace and annealed at 800°C (lime-shale series) and at 900°C. (dolomite-shale series) for two hours.

The petrographic analyses were made with grains, using the methods employed at the Geophysical Laboratory.[4] No thin sections were made as the structure was fine enough to be clearly shown on small grains.

LIME—SLAG SERIES

The chemical analyses of the raw materials and finished slag in this series are tabulated in Table II of part A, Nos. 4 to 8 inclusive.

Slags Nos. 4 and 5 megascopically were black opaque in thicker sections and green translucent when thinner. They resembled the rock, obsidian, greatly, showing a high vitreous luster, conchoidal fracture and were very brittle. Under the microscope they were colorless, isotropic and showed absolutely no beginnings of crystallization. The index of refraction of No. 4 was 1.636 ± 0.002 and of No. 5 was 1.640 ± 0.002.

Beginning with No. 6, the slags of this series showed more or less crystallization. As to to be expected the unannealed slags showed a great preponderance of glass. Annealing had the effect of decreasing its quantity to quite an extent and increasing the crystallization. In most cases the number of crystallization centers was increased considerably while the actual size of the crystals was affected to a less degree.

The crystallites in the unannealed slabs took on very interesting forms. They occurred as aggregates of slender fibers, some of which radiated from a common center (radialites), others arranged themselves like the ribs of a fan (dendritic); still others were in the shape of plumes. The individuals were exceedingly small and an adequate optical examination was oftentimes impossible, except on those crystallites with more advanced development.

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[4] *Jour. Ind. Eng. Chem.* 3, No. 4, 26–31.

The unannealed slags, Nos. 6, 7 and 8, were olive green in color and contained black streaks of glass; No. 6 showed a fine grained stony structure; Nos. 7 and 8 showed a coarser grained structure. In No. 8, due to conditions of cooling alternative lamellae of crystalline material and glass were noted. The fracture in each case was conchoidal and uneven tending toward the former in No. 6 and 7 and toward the latter in No. 8.

Under the microscope No. 6 (unannealed) consisted mainly of glass (with an index of refraction of 1.651 ± 0.002) containing radialites, dendritic and plume shaped aggregates, of which the individuals were prismatic in development. The latter showed a fairly low double-refraction (gray to yellowish red of the first order being noted) and a mean index = 1.625. It was biaxial and the character of the double refraction was negative. Cleavage was noted in a few instances and the substance showed an inclined extinction with a small extinction angle. This is the mineral wollastonite ($CaO.SiO_2$).

Number 7 (unannealed) showed less glass than No. 6 and contained much more crystalline material, the individual crystallites being also larger. However the aggregates show the same general structure. Wollastonite was observed but in addition to this were noted a few small low doubly refracting crystallites tending toward a square cross-section. They were too small for obtaining an interference figure, but showed a negative principal zone and a mean index of refraction equal to 1.66. The observed properties correspond closely with those of the mineral gehlenite. According to Dana's System (p. 476) the formula of gehlenite is $3\,CaO.Al_2O_3.2SiO_2$. The Geophysical Laboratory, in their work on the ternary system $CaO\text{-}SiO_2\text{-}Al_2O_3$, have identified a synthetic compound $2CaO.Al_2O_3.SiO_2$ resembling gehlenite very closely in crystallization and optical properties.[5] The difference in composition may be due to either foreign material in the mineral analyzed, solid solution, or even both.

Number 8 (unannealed) showed much less glass than No. 7 (unannealed). The constituents were the same, but the amount of gehlenite had increased considerably and larger sized crystals

[5] *Jour. Ind. Eng. Chem.* 3, (April, 1911).

were noted. Interference figures obtained on these showed a uniaxial figure with the character of the double refraction negative, which again agrees with the mineral gehlenite.

Number 6 (annealed) showed a stony structure, brownish in color near the surface and a more coarse grained structure as the center of the specimen was approached, due to the slower cooling. The cleavage of the outer part was conchoidal, that of the inner part uneven. Under the microscope it still showed glass, but the quantity was much less than in the unannealed specimen. The number of crystallites increased greatly, the size had increased in general, but to a lesser degree. Radialites, dendritic and plume-shaped aggregates were still found, but the tendency was for crystals to intergrow irregularly. Wollastonite was found in prismatic crystallites and gehelenite was also observed here in a small amount. Very fine grained aggregates of a low doubly refracting material showing a mean index of about 1.58 were noted. They had the appearance of the beginning of crystallization of a basic plagioclase (near the composition of anorthite). It could not be more accurately identified and occurred only in a small amount.

Number 7 (annealed) was brownish in color, showed a coarser grained texture on the whole than No. 6, but it contained dark seams of glass. Under the microscope it showed the same structure as No. 6 and contained less glass. Wollastonite was observed also in lesser amounts, while gehlenite had increased somewhat. Careful search did not reveal any basic plagioclase.

DOLOMITE—SHALE SERIES

The analyses of these slags are given in Table II, part A, Nos. Nos. 9–15.

Of the unannealed slags No. 9 was the only one which showed no signs of crystallization. Black opaque in thicker specimens, green translucent in thinner ones, it showed a high vitreous luster a conchoidal fracture resembling obsidian. Under the microscope it was colorless, isotropic and had a refractive index, of 1.607 ± 0.002.

The remaining unannealed slags of this series showed more or less crystallization. The more basic the slag the less vitreous it appeared.

Number 10 (unannealed) was black to greenish black in color, showed devitrified spots (indicating crystallization) and a conchoidal fracture. Under the microscope it consisted mainly of glass with a refractive index equal to 1.611 ± 0.002 containing dendritic aggregates of crystallites. These were of two kinds, long acicular crystallites, having a low double refraction (low gray and white interference color) and a mean index of 1.57 ± 0.005. This compound has the optical properties of a plagioclase with a composition in the neighborhood of anorthite ($CaO.Al_2O_3.2SiO_2$). There were also noted crystallites showing prismatic development. A few cleavage cracks were observed parallel to the prism axes. This compound was low doubly refracting, the maximum interference color being white of first order. It showed parallel extinction, had a mean index equal to 1.670 ± 0.004, and was biaxial with a positive optical character. These optical properties agree very closely with that of the mineral enstatite $(MgFe)SiO_3$, the higher index of refraction indicating the presence of FeO in the compound.

Number 11 (unannealed) resembled No. 10 (unannealed) in appearance, both megascopically and microscopically. A smaller amount of glass with an index equal to 1.614 ± 0.002) was noted, and the crystallites of enstatite were somewhat larger in size. Anorthite was also noted.

While No. 12 (unannealed) resembled the more acid slags in appearance the crystallization proceeded farther. The glass, which was still by far the predominating constituent, had an index of refraction equal to 1.619 ± 0.002. The crystallites of feldspar and enstatite were noted, but the former appeared to be disappearing. In addition, a few small rounded grains were observed showing second order interference colors, with a mean index equal to 1.67. These seemed to be the mineral olivine [$2(Mg,Fe)O,SiO_2$] although they were too small to obtain more optical data.

Number 13 (unannealed) was greenish black in color and showed a stony crystalline structure with a conchoidal fracture. Under the microscope a more advanced crystallization was noted than in No. 12, the constituents were the same, but the compound identified as olivine grew both in development and quantity. Interference figures obtained were biaxial with the character of the

birefringence positive, showing conclusively that this compound was olivine.

Number 14 (unannealed) resembled No. 14 megascopically. Under the microscope there was less glass noted than in No. 13, and the olivine crystals were well developed and plentiful. In addition were noted small crystals with square cross-section and sometimes showing prismatic development. They had a low double refraction, a mean index equal to 1.66 and were uniaxial negative. These optical properties agree very closely with those of the mineral gehlenite.

Of the annealed slags of this series No. 9 showed the least crystallization. It had the appearance of an obsidian with a thin external coating showing irridescence. Under the microscope the interior was a glass while the irridescent coating showed the beginnings of crystallization in the nature of fibrous aggregates of crystallites whose identity could not be definitely established. They were colored yellowish which would seem to indicate a segregation of iron.

In the remainder of the annealed slags of this series the amount of glass was less than that of the unannealed slags, while the amount of crystalline material increased, but as in the case of the lime series the size of the individual crystals increased, but to a lesser degree. While radialities, dendritic and plume-shaped aggregates were noted the tendency on annealing was for the formation of irregular intergrowths without any definite orientation.

Number 10 (annealed) was greenish in color, had a dense stony structure and a conchoidal fracture. Microscopic examination revealed, besides glass, long prismatic crystallites of plagioclase which from their mean index of refraction, 1.57, medium low birefringence, biaxial interference figure, negative optical character and large extinction angle pointed to a composition in the neighborhood of anorthite. Iron bearing enstatite was also observed. In addition there was noted a third type, augite, showing prismatic development, fairly high double refraction, inclined extinction, large extinction angle, mean index equal to 1.72, biaxial interference with positive optical character. This was present in small quantities.

Number 11 (annealed) was greenish in color, iridescent in

spots, had a glassy to stony structure and a conchoidal fracture. It contained, besides glass, crystals of enstatite which were larger than those observed before, also augite showing fairly good prismatic development. The basic plagioclase was most poorly developed and was much intergrown.

Number 12 (annealed) was for the most part greenish in color, now and then black, glassy irregular veins were observed. It was dense, stony and showed a conchoidal fracture. It contained less glass than did No. 11 (annealed), well developed crystals of enstatite and augite and intergrown crystallites of plagioclase. There were also noted a few crystals of olivine, showing characteristic prismatic form. They had a medium high birefringence, a mean index of refraction equal to 1.67, parallel extinction, biaxial figure with positive optical character. Accurate double refraction measurements on a crystallite orientated parallel to (001) gave $\gamma - \alpha = .026 \pm .003$, which is somewhat lower than that of olivine and would seem to indicate a chemical composition between olivine and monticellite ($CaO.MgO.SiO_2$).

Number 13 (annealed) megascopically appeared to be identical with No. 12 (annealed). Microscopically it showed less glass, more augite and more olivine than No. 12. It contained very few plagioclase crystallites and little enstatite. In addition were noted a few uniaxial negative grains of gehlenite showing weak double refraction and a mean index equal to 1.66.

Number 15 (annealed) was yellowish green in color on the surface and grayish in the interior. It possessed a dense, stony structure and a fracture which was conchoidal to uneven. Under the microscope it revealed a small amount of glass, considerable olivine, an increase in the gehlenite content over No. 13 (annealed). Augite was also noted, but neither anorthite nor enstatite could be definitely found.

It is interesting to note that garnet was not observed in the lime-shale series, agreeing with the observations of Vogt[6] who reports that it has been found only once or twice in slags. Spinel was absent from the dolomite-shale slags, the percent of Al_2O_3 probably being too low.

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[6] *Handbuch der Mineralchemie von Doelter* 4, p. 933.

It was not deemed advisable to obtain the indices of refraction of all the glasses, but those taken indicated that the greater the basicity the higher the index. This agrees with the results of Tillotson,[7] although the soda lime glasses he examined were more acid in character and not aluminous. The glasses of the dolomitic slags showed also slightly lower indices than the glasses of the corresponding lime slags.

The more basic the slag (in these series) the more was the tendency toward crystallization. Annealing reduced the content of glass and increased the crystallization. In general the basic slags of the limestone series were coarser grained than the corresponding dolomitic slags.

DISCUSSION

Mr. Stull: In some work that is being done now in an attempt to produce cheap glasses, we have been doing some work along this line, a work that was started about two years ago. The work consists in obtaining the eutectic between a clay and whiting and a eutectic between sand and clay then obtaining the eutectic of those two. We have succeeded in getting some very beautiful glasses and certain glazes and mats much more famous than the famous Albany slip or Michigan slip and much cheaper. We have tried surface clays, shales and numbers of fire clays and are trying others now.

Mr. Purdy: I would just like to ask for information on the possible suggestion that paving bricks may be made by casting from melts, artificially made—would there be any commercial possibility of that?

Mr. Bleininger: That is what we are considering.

Mr. Purdy: Making your own melts, not depending on slags.

Mr. Bleininger: Exactly so; you could use slags if you had them available.

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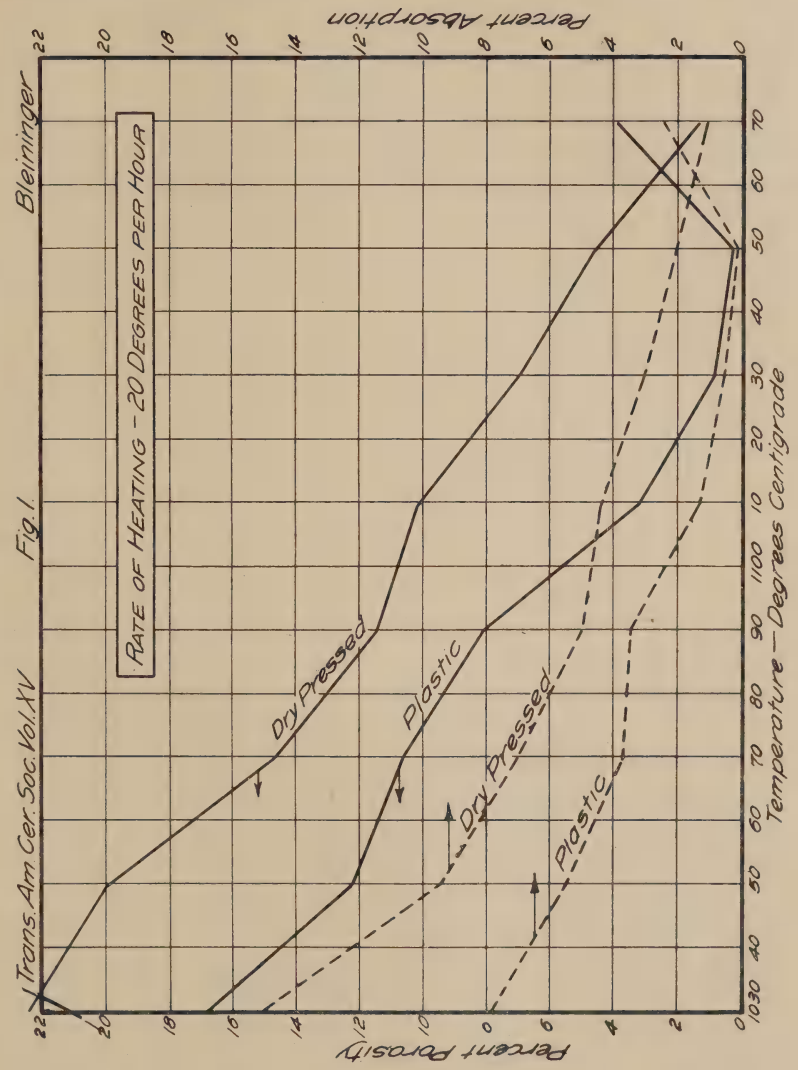
[7] *Jour. Ind. Eng. Chem.* 4, 246–9 (April 1912).

THE TEMPERATURE-POROSITY RELATION OF A CLAY PREPARED IN THE PLASTIC AND IN THE MOIST CONDITION

BY A. V. BLEININGER, PITTSBURGH, PA.[1]

In determining the porosity-temperature relations of a clay, the initial physical condition is of considerable importance as regards the course of the curve. The information to be derived from such a test is for this reason bound to be influenced to a greater or less extent by the size of grain, method of molding, etc. In order to illustrate the extreme limits possible in such work, the following short experiment was made. A lot of Canton, Ohio, shale, well-known for its safe vitrifying properties, was thoroughly mixed in the dry, ground state so that it truly represented a uniform sample. Part of this material was made up unto brickettes in the plastic state, part was dry-pressed in the moist condition, containing about 9 percent of water. The specimens made from the plastic clay weighed about 80 grams when burned, the dry-pressed trials about 40 grams. All of the dried brickettes were placed in the kiln close together and fired at the rate of 20°C. per hour. After burning, the usual absorption and porosity determinations were made. The results are shown graphically in the accompanying diagram. As is to be expected, the initial porosity of the dry-pressed body is considerably higher than that of the shale molded in the plastic state. Starting with 22.8 and 16.8 percent porosity, respectively, the contraction of both kinds of specimens proceeds fairly uniformly and progressively down to about 3 percent. At this point the contraction of the plastic body slows up. All along the two curves however points of equal porosity are separated by a considerable temperature interval, which becomes greater as the 3 percent line is approached. Thus a porosity of 6 percent is reached by the plastic molded body at 1100°, by the dry-pressed body at 1138°. Similarly, 3 percent porosity is obtained in the first case at 1111°, in the second at 1159°. Within the temperature limits employed the condition of non-absorption is not reached at all by the dry-

[1] By permission of the Director, Bureau of Standards.


Percent Absorption
Percent Porosity
Temperature—Degrees Centigrade
Rate of Heating - 20 Degrees per Hour
Dry Pressed
Plastic
Dry Pressed
Plastic
Trans. Am Cer. Soc. Vol. XV
Fig. 1
Bleininger

pressed body, while the plastic molded clay not only becomes impervious but even decidedly overburned at 1170°.

Here we have a case where the influence of physical factors is shown most prominently. The identical body presents an entirely different behavior according to whether it is made up in the plastic or the dry-pressed condition. At the same time the well-known practical observation that dust-pressed clays require a higher maturing temperature is confirmed. If the two conditions of preparation were not known, the two curves would be considered to represent two clays of varying behavior.

USE OF THE CASTING PROCESS FOR LARGE CLAY WARES

BY C. J. KIRK, NEW CASTLE, PA.

The process of casting sanitary earthenware is new. Some four years ago, on account of the difficulty in securing competent workmen in the sanitary pottery line and the stringent rules of the union in regard to apprentices preventing us making our own, we decided to try out the casting method for making plumbers' earthenware. We had heard that it was being done successfully in England and corresponded with parties there who claimed a patent on the mix. After some negotiations, they sent a representative here and we agreed, if their patent was a valid one, to use their process and pay them a royalty. On investigation we found that the patent covered the using of certain proportions of silicate of soda and carbonate of soda in the slip. Some friends in England looked into the matter for us, and they reported that soda ash or most any preparation of soda could be substituted for the carbonate and that none of the manufacturers in England were paying any royalty and were not recognizing the patent as a valid one. We then started in to experiment and our first attempt was along these lines as shown in Fig. 1. The trap and water way was formed by the mold and left a depression in the side of the closet that was objected to by the trade as a dirt catcher and unsanitary. We then tried to overcome this by setting pieces or brackets in the sides but this gave us trouble with our workmen, requiring skill to do the work properly and thus getting away from our object in using the casting method, which was to use unskilled labor in producing the ware. We then experimented along the lines of casting the trap separately and setting it in the mold and casting the closet around it as shown in these photos. This looks simple enough but it took a long time and a great many experiments to determine the proper consistency to have the trap so that it would not disintegrate and go to pieces when the liquid slip was poured into the mold and surrounded the trap on all sides. The difficulties at times seemed too great to overcome, and we thought several times we would have to give up; but by keeping everlastingly at it, we have at last been successful in turning out very fine ware.

We have been granted a patent on this method of casting ware, that is, casting the trap and setting it in the mold.

Figure 2 shows one of the molds that we use. This shows the best method of holding the molds together. They are split down the center and have the trap set in and the slip is poured in the top of the mold. The flushing rim is cast separately. The slip is run around the buildings in 2 inch galvanized pipe and a hose is used to convey it to the molds as shown in Figure 3. It is allowed to remain in the molds about two hours and then is drawn off.

Figure 4 shows the foot and trap in place. We cast the foot and the trap and set it in the mold. This photo shows half the mold with the trap and foot set in place; the other half of the mold is put on as you saw it in Figure 2 and is all filled in with slip. The slip runs down the sides and amalgamates with the trap and foot. The mold is made of plaster of paris; it is absorbent and the clay casts around this section about $\frac{3}{8}$ of an inch thick. You can vary that by leaving it cast a shorter or longer time.

Figure 5 shows the mold with one-half taken away, the closet just as it appears in the mold, ready to take out.

Figure 6 shows the closet with the two halves separated and the closet just as it appears. The fin has be to trimmed off the back and front, and the roll that the top is put on with is finished with a pallette. That is all the work we do on the closet. We have to cast the top separately on account of piercing the holes underneath to make the flush.

Figure 7 shows you the way the inside of the closet is formed.

Figure 8 shows the way the top is cast, and then holes are punched all around the bottom to flush the closet. After the holes are punched the top is put on with a roll. It stays in the mold until it is placed on top of the bowl. The closet I have just shown you is called a washdown closet; it is the closet that is used largely. The better closets are called siphon jets. They are cast with waterways that come down the sides to a jet at the bottom of the closet; this gives a quicker action and permits using a deeper water seal.

Figure 9 shows the front of the trap that is set in for the mold. Figure 10 shows the side of the trap; there is a depression in it, you see, that brings the waterway down to this jet. That

Figure 1

Figure 2

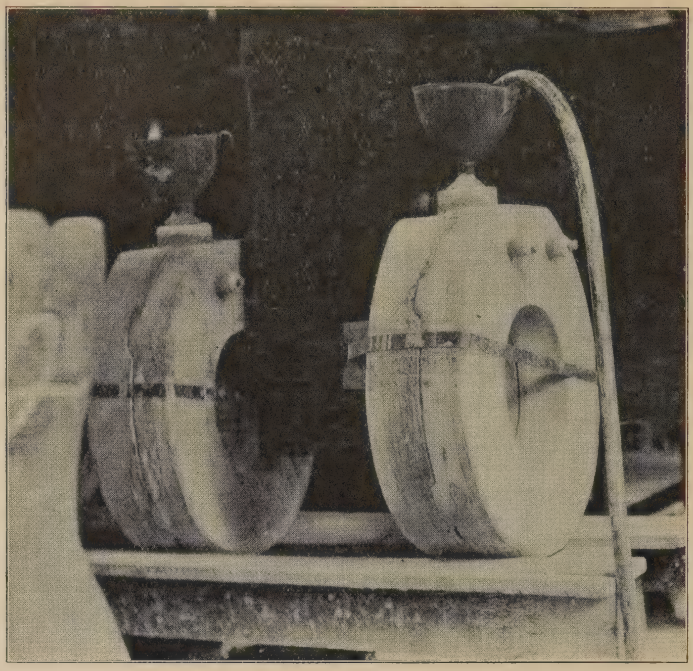


Figure 3

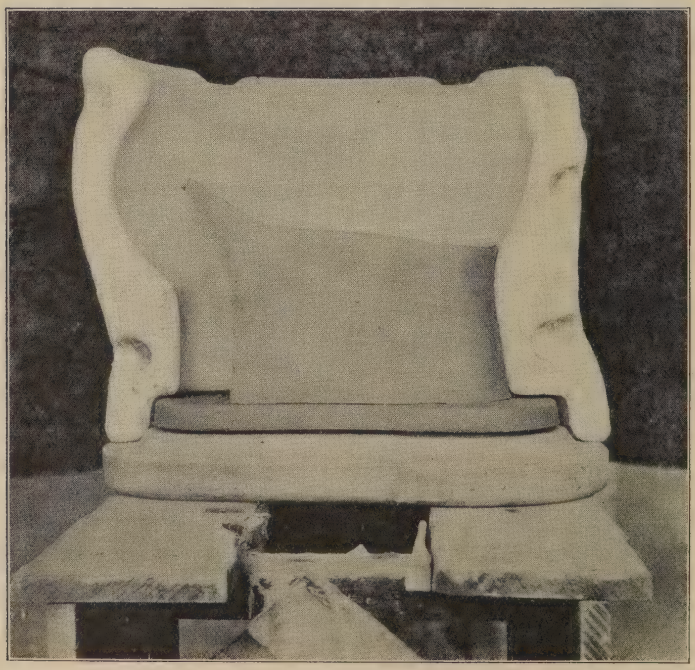


Figure 4

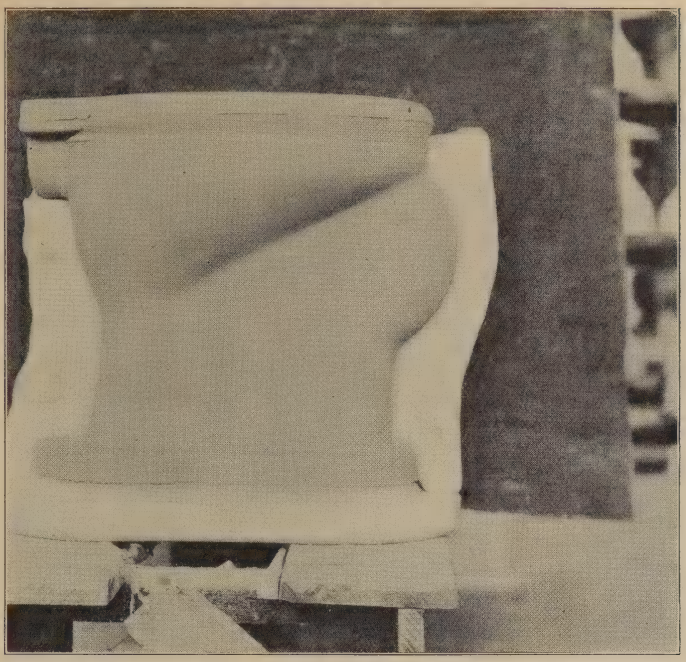


Figure 5

Figure 6

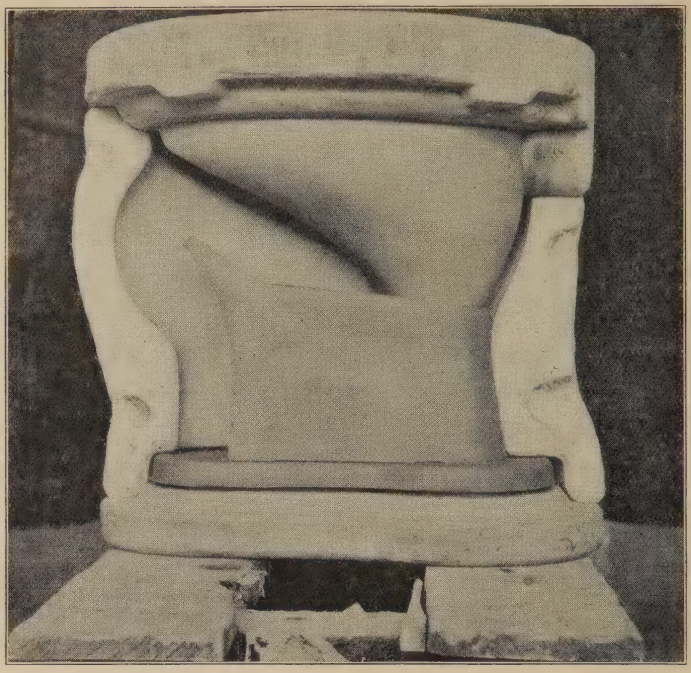


Figure 7

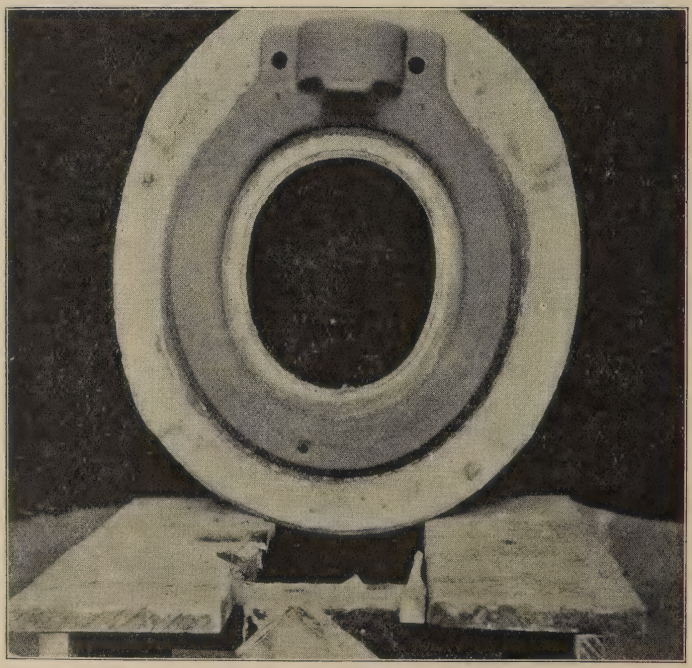


Figure 8

Figure 9

Figure 10

Figure 11

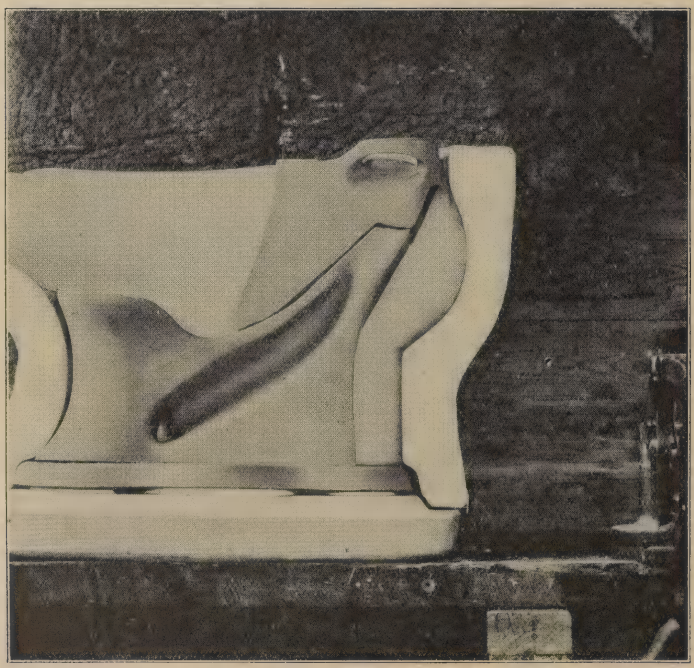


Figure 12

Figure 13

Figure 14

is in the front of the trap, and when the mold sets up against it, a wall is cast on the outside, leaving a waterway down to the jet. The mold at the top has a depression that brings the water around the trap down to this passage.

Figure 11 is the trap sawed in two; the front is hollow, this part of the trap is left hollow, and there is where the water comes in. The jet hole is at the bottom of the trap. The jet throws a stream of water up over the top of the trap to give it the siphon action.

Figure 12 shows the trap set in the mold ready to cast. We cast this in two pieces, the trap and the top. The water is conducted down on both sides of the trap. This is called a twin concealed siphon jet.

Figure 13 shows the closet cut in two in the center. The waterway comes down the sides, and there is a jet hole that throws the water up through this passage to discharge it. The top is put on afterwards, the same as on the washdown closet, and the holes are punched here to flush the inside of the bowl.

Figure 14 shows the complete closet. This is the waterway; it shows on the upper part. It then goes down the inside of the trap. At first we put this jet passage on the outside of the closet, and that entailed casting in a separate piece and putting on with a roll; but as we did not have expert workmen, we had trouble in attaching. It had to be put on very carefully; so we tried out the method I have shown you, of casting it all in one piece. The closets are made all complete. When the workmen take the molds away, the passages are all formed by the mold and trap as shown.

DISCUSSION

Mr. Ward: I would like to ask Mr. Kirk to what cone he fires.

Mr. Kirk: Cone 9, down. We are using a 40 percent flint in our body, and I don't think that has ever been done before in the sanitary business. We could not do it if we were pressing. My friend, Mr. Mayer, who is the father confessor for all the potters in the country and who is a very present help in time of trouble, recommended that we try that. We are doing it successfully, but have to fire our ware very hard to get good results.

Mr. Ward: In the first place, you show it made up in two sections; how do you unite those—with a slip joint?

Mr. Kirk: No, it is made in two sections, and put together with a roll, the same as in pressing.

Mr. Ward: In firing, do you have to rely on the kiln uniting the two pieces?

Mr. Kirk: No, they unite when cast in the mold.

Mr. Simcoe: Just to get a comparison with the ordinary pressing, I would like to ask how many pieces can be made, per man by this process.

Mr. Kirk: Our men are unskilled workmen, that is, they are not practical workmen in the pottery business; they are Italians and people we pick up around town, and they make nine washdown closets per day. The ordinary presser makes four. On siphon jet closets, the unions restrict their workmen to making three a day. Our men make eight a day; they could make ten a day, if we would let them, but they would be apt not to finish them as well as we require. That is about the proportion, about twice as many by this method as the old method, and the price is correspondingly lower, that is, we pay 40 cents each for making the washdown closets and the regular price for pressing them is 90 cents. On the siphon jet, we pay 60 cents for casting them and the regular price is $1.85 or $2 for pressing. So it is quite a saving in cost of manufacture.

Mr. Ward: May I ask how thick is the thickest section you can get in the casting process, without cracking?

Mr. Kirk: Well, there are some parts in our siphon-jet closet that are an inch and a half thick.

Mr. Ward: Is there cracking at points that are unequal in thickness?

Mr. Kirk: We don't have much trouble that way; the greatest trouble we have in cracking is from the liquid slip running over the cast slip. They are drained from the bottom and if any liquid slip runs over the cast slip and dries there, it cracks. That's the greatest trouble we have.

Mr. Watts: Mr. Ward, this is not a solid porcelain proposition? Your body is more of a fire clay base, is it not, Mr. Kirk?

Mr. Kirk: Oh no, absolutely not; regular vitreous china; the same body Mr. Mayer uses in making his hotel ware.

Mr. Watts: Well, I beg your pardon. It is practically the same proposition you were figuring on.

Mr. Ward: Yes, I have been working along that line and experienced somewhat the same trouble as Mr. Kirk. However, when I try to vary the thickness of the wall, I get in trouble.

Mr. Kirk: Where one part dries faster than another, you are apt to develop a strain, but if you will cover up the thin parts and let them dry gradually you will not have any trouble.

Mr. Purdy: Do I understand that you cast a piece and put it into a mold and cast on to it?

Mr. Kirk: Yes sir.

Mr. Purdy: Do you have to be particular how dry that piece is that you put into the mold?

Mr. Kirk: We have to be very careful, and that is one of the hardest things to overcome. We worked six months to get the trap to a consistency where it would not disintegrate and go to pieces when we poured the slip around it. That is the secret of the process and that is the reason that I am not very much averse to showing people how we do it, because they couldn't do it after being shown without special instructions. I will state that I have a patent on the process of setting the trap in the mold and pouring the slip around it. This is new and novel, and other manufacturers are negotiating to use this process and pay royalty for using it.

Prof. Staley: Do you have any particular trouble from the disintegration of your molds, and is there any particular salt or mixture of salts less liable to cause harm to your mold than others?

Mr. Kirk: We have no trouble at all with our molds. We had at first, but we overcame that by getting the mixture of plaster to the right consistency. We have molds that have turned out thousands of closets and are still in use.

SOME CHEMICAL REACTIONS OF INTEREST TO THE PLATE GLASS CHEMIST

BY F. GELSTHARP, CREIGHTON, PA.

In 1912, I presented a paper with the above title, and promised to give the results of further investigations relating to some of the reactions of which published information was lacking. Each of the reactions was designated in the previous paper by a number; and in this paper, I will refer to them by the same number.

Out of 44 reactions, I selected 14 for investigation and disposed of 5 (3, 8, 10, 20 and 36). I have made investigations of a few of the remaining reactions (18, 22, 27, 31, 43).

18. SODA ASH AND WHITE ARSENIC

One hundred grams Na_2CO_3 were heated slowly in an open crucible with 5 grams of As_2O_3,—4.76 percent. The temperature was gradually raised to 900°C., that is, about 50° above the melting point of Na_2CO_3. The escape of As_2O_3 fumes was noticed. During the melting there was an energetic boiling action or evolution of gas which later subsided. The conditions of the experiment were such that free oxidation could take place. An analysis of the product gave:

$$\left.\begin{array}{ll} As_2O_3 & 0.468 \text{ percent} \\ As_2O_5 & 3.512 \text{ percent} \end{array}\right\} = 3.49 \text{ percent } As_2O_3$$

These figures show a loss by volatilization of 26.68 percent of the original As_2O_3. This loss appeared to take place only while the temperature was being slowly raised; judging by the amount of fuming which occurred. And from the analysis one would have to conclude that the As_2O_3 has become oxidized and combined with Na_2CO_3 forming Na_3AsO_4 thus:

$$As_2O_3 + 3Na_2CO_3 + O_2 = 2Na_3AsO_4 + 3CO_2$$

It has been stated that As_2O_3 in a glass batch reacts thus:

$$5As_2O_3 = 3As_2O_5 + 2As_2$$

the metallic arsenic going off as such and the As_2O_5 being able to then act as an oxidizer, being converted into As_2O_3, and the process repeating itself until finally the whole of the arsenic leaves the glass as metallic arsenic.

Applying this assumption to our experiments and considering there is nothing to oxidize, we could not possibly have more than 2.85 percent of As_2O_3 remaining in the melt. Instead, we have 3.49 percent, so that we must reject this latter theory in favor of the former.

22. SALTCAKE + WHITE ARSENIC

One hundred grams were heated slowly in an open crucible with 5 grams = 4.76 percent of Na_2SO_4. The temperature was slowly raised to 940°C.; that is, about 50° above the melting point of Na_2SO_4. Very strong fuming took place on raising the temperature above 260°C., but no boiling action was noticed while the mass was melting. In cooling, the product was found to be neutral to litmus; it was analyzed and found to contain:

$$As_2O_5 = 1.13 \text{ percent} = 0.97 \text{ percent } As_2O_3$$

The loss of As_2O_3 was therefore 79.20 percent of the original.

If the Na_2SO_4 had been reduced, we would expect to find some sulphur compounds such as polysulphide of soda or sulpharsenate of soda. These were not present; but if they had been formed, the compound would undoubtedly be immediately destroyed by oxidation leaving Na_3AsO_4. In this way the presence of arsenic in the resulting melt may be accounted for.

From the result of the foregoing, the original intention of repeating the experiment in a tightly closed crucible was abandoned for the quick volatilization of the As_2O_3 would not give the required conditions. And, since it was found that in investigation No. 18 As_2O_3 formed with Na_2CO_3 a fairly stable compound (Na_3AsO_4), it was decided to use this salt with Na_2SO_4 in a tightly closed crucible subjected to the same temperature as before (940°C.). This failed to produce any decomposition of the Na_2SO_4, and the melt was not alkaline. Such a result is only what might be expected because the arsenic here is present as pentoxide and not capable of further oxidation.

Na_3AsO_3, in which the arsenic is present as trioxide, was now mixed with Na_2SO_4. The crucible was tightly closed, and the temperature raised slowly to 940°C. The result of this experiment was a very decided reaction.

The Na_2SO_4 was reduced, sulphur compounds were formed, the melt was of brownish yellow color and strongly alkaline. On treating with acid, some sulphide of arsenic was precipitated and sulphuretted hydrogen (SH_2) gas was liberated.

The compounds formed in this reaction must have been a sulphide of sodium (Na_2S or Na_2S_n) with arsenate and sulpharsenate of sodium (Na_3AsO_4 and Na_3AsS_4) thus:

$$Na_2SO_4 + 4Na_3AsO_3 = Na_2S + 4Na_3AsO_4$$
$$4Na_2SO_4 + 13Na_3AsO_3 = Na_3AsS_4 + 12Na_3AsO_4 + 4Na_2O, \text{ or}$$
$$3Na_2SO_4 + 10Na_3AsO_3 = Na_2S_3 + 10Na_3AsO_4 + 2Na_2O$$

27. LIMESTONE + WHITE ARSENIC

Five grams of As_2O_3 = 4.76 percent, was heated in an open crucible in an oxidizing atmosphere with 100 grams of $CaCO_3$. The temperature was slowly raised to 1090°C. Some fumes of arsenic were noticed while the temperature was being raised. The product was analyzed and found to contain, 3.48 percent of As_2O_5, = 3.00 percent As_2O_3. This shows a loss of 36.97 percent of the original As_2O_3.

$$3\,CaCO_3 + As_2O_3 + O_2 = Ca_3(AsO_4)_2 + 3CO_2$$

This was now repeated, using CaO in place of $CaCO_3$. No fumes were noticed during the heating. The product was tested and found to contain the whole of the original amount of As_2O_3 as, As_2O_5.

$$3CaO + As_2O_3 + O_2 = Ca_3(AsO_4)_2$$

These experiments give important information to the glass chemist, as they throw much light on the deportment of arsenic in a glass batch. The use of As_2O_3 in a glass batch has sometimes been ridiculed by chemists, especially when carbon is also present. It was considered that As_2O_3 was so volatile that none could remain in the melt, and in presence of carbon the As_2O_3 would be reduced

to metallic arsenic and escape as such. We know that some of the As_2O_3 is lost by reduction due to carbon.

$$2As_2O_3 + 3C = 2As_2 + 3CO_2$$

I have found that in the case of plate glass as much as 56 percent of the original As_2O_3 remains in the finished glass, and it is interesting to learn that this is all present as As_2O_5, none as As_2O_3. The glass melting goes on under reducing conditions, and if the As_2O_3 did not act as a reducing agent in this case, it would not finally be present as the higher oxide As_2O_5. The conclusions to be drawn from these results are that As_2O_3 in a plate glass batch acts as a reducing agent, becoming converted into As_2O_5. And, although As_2O_3 is volatile at 200 to 250°C., it will remain in the melt by combining with Na_2O or CaO forming arsenates which are comparatively stable. And a portion of the As_2O_3 is lost by the reducing action of carbon.

31. SAND + SODA ASH + LIMESTONE

This mixture forms silicate of soda and lime but only in certain proportions does it form a uniform glass. Some few experiments have been made to determine approximately the limits for the proportion of the lime possible. The following table gives the results:

Na_2O	CaO	SiO_2	
0.67	0.33	2.00	Clear glass
0.60	0.40	2.40	White flakes on surface
0.57	0.43	2.57	White scum on surface
0.49	0.51	2.43	White scum on surface
0.40	0.60	2.40	White scum on surface
0.33	0.67	2.00	White scum on surface

This work is very incomplete but the results so far tend to show that when the ratio of Na_2O to CaO is less than 2 : 1 we are not likely to get a uniform glass.

The thick white scum which has a great tendency to remain on the surface of the pot has been analyzed; and I find it to be a crys-

tallized double silicate of lime and soda, approximating the following composition:

Na_2O		CaO		SiO_2
0.585		0.415		5.100
$(Na_2O$	$8SiO_2)$			
$2CaO$	$3SiO_2$	or $3Na_2O$	$2CaO$	$27SiO_2$

This may be a definite compound silicate. I have found that the addition of a small amount of sulphate will prevent its formation, or perhaps I should say that Na_2SO_4 decomposes it so that it is incorporated in the melt. An optical examination of this material may throw some light on its composition.

I do not feel sure that it is not simply a mixture of silica and a glass, but the analysis was made of the solid white body, which did not appear to contain any glassy substance.

43. SAND+SODA ASH+SALTCAKE+COMMON SALT+LIMESTONE + CHARCOAL + WHITE ARSENIC

I have little to add to what I have already stated. As_2O_3 does not act as an oxidizer of iron and entirely volatilize. It appears in all the reactions we are concerned with as a reducing agent.

Regarding the possibility of Na_2SO_4 being reduced to Na_2SO_3 in a glass melt, I have further attempts to try and prove if this is possible. Heating C. P. Na_2SO_3 in atmospheres of CO_2, SO_2, CH_4, H or N gas fails to prevent its decomposition in every case. It was thought that the presence of Na_3AsO_3 or Na_3AsO_4 might make it possible; all attempts were without success. The sulphite breaks down in every case with formation of sulphate and sulphide, except that in the case of SO_2, the SO_2 is reduced to sulphur and the sulphite takes up the oxygen to form sulphate of soda. I now feel convinced that there is no possibility of sulphite of soda being present in the melting of a glass batch.

I hope that the other suggestions for investigations as outlined in my 1912 paper will, if possible, be proceeded with and discussed in the near future.

NOTE SUBMITTED AFTER READING THE PAPER

Prof. Silverman: Mr. Gelstharp's claims that arsenious oxide acts as a reducing agent were strikingly shown in some experiments recently made. An article which appeared in *Sprechsaal* a number of months ago advocated the use of lump arsenic for the removal of black streaks in glass. The statement was made that the fused oxide, having a greater specific gravity than the molten glass, would sink to the bottom, and gradually vaporizing, exert a chemical action which should result in the disappearance of the streaks. They did disappear, but the glass became seedy and turned green. The seeds did not disappear even on long standing, and the green color was undoubtedly due to a reducing action by the arsenic compound. I can say nothing regarding the reactions given by Mr. Gelstharp, but am inclined to believe that arsenious oxide would generally act as a reducing agent.

NOTES ON THE CAUSE OF MATNESS IN GLAZES

BY A. R. HEUBACH

INTRODUCTION

These experiments were originally not intended for publication, and, therefore, they are not so extensive as they ought be to. I did not do any work along petrographic lines, since my results seemed to justify the assumption that matness is due to crystallization.

I was taught years ago by Dr. Pukall that true mats had to melt the same as any glassy glaze and that matness was caused by crystallization on cooling. My observations with raw leadless mats for higher temperatures seemed to bear out this contention. In one of the terra cotta plants with which I was connected, we used to draw trials at the finish of the firing, and I had, therefore, an opportunity to observe the behavior of different types of mat glazes under these conditions. As a matter of fact, I did not find one mat glaze, barium mats included, which did not form a glassy coating when cooled suddenly, although they gave good true mats when cooled slowly in the kiln.

As far as I am aware, no case is known where amorphous material separates from an igneous solution, and, therefore, I felt justified in assuming that, in this type of mat glazes, matness is due to crystallization.

EXPERIMENTAL WORK

Production of First Samples. Since all the glazes included in last year's discussion contained lead and were fired at a low or medium temperature, it did not necessarily follow that they also must be crystalline. As I had never had an opportunity to study the effect of quick cooling on this type of mat glaze, I decided to make a few experiments with some of the glazes which were classified as "immatures" in last's year's discussions. I included one of the leadless high-temperature mats in order to be able to compare it directly with the others. In order to determine whether matness occurred at a definite point or whether it be formed gradually, I decided to draw trials at different intervals during the cooling process.

I made the following glazes:[1]

No. 1.	0.70	CaO	0.7 Al_2O_3 2.7 SiO_2
	0.30	K_2O	
No. 2.	0.30	CaO	0.35 Al_2O_3 1.675 SiO_2
	0.15	K_2O	
	0.55	PbO	
No. 3.	0.344	CaO	0.50 Al_2O_3 1.466 SiO_2
	0.088	KNaO	
	0.475	PbO	
	0.093	CuO	
No. 4.	0.200	CaO	0.35 Al_2O_3 1.6 SiO_2
	0.225	K_2O	
	0.575	PbO	
No. 5.	0.15	K_2O	0.233 Al_2O_3 1.9 SiO_2
	0.10	PbO	
	0.10	ZnO	
	0.30	BaO	
No. 6.	0.175	KNaO	0.33 Al_2O_3 2.0 SiO_2
	0.500	PbO	
	0.075	CaO	
	0.250	BaO	

No. 1 was fired to cone 9; No. 2 to cone 4; No. 3 to cone 3; No. 4 to cone 1; No. 5 to cone 2; and No. 6 to cone 02. The different burns took from twenty to twenty-four hours. No special precautions were taken to cool the kiln slowly, the fire was shut off at the finish and the kiln left to cool naturally. A preliminary test showed, that after two hours cooling, matness was almost complete.

Now I made up four tiles of each glaze and put them in the kiln so that I could easily draw them out. One sample was drawn at the finish of firing, one after half an hour and another one after one and a half hours. The fourth trial I left to cool in the kiln.

The trials were mounted on a board in the order in which they were drawn, and you may easily compare the behavior of the different glazes.

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[1] No. 1, Private notes; No. 2, Purdy, *Trans. A. C. S.*, Vol. XIV, p. 675; No. 3, Miss Cooke's, *Trans. A. C. S.*, Vol. XIV, p. 696; No. 4, Binns, *Trans. A. C. S.*, Vol. V, p. 52; No. 5, Orton, *Trans. A. C. S.*, Vol. X, p. 567; No. 6, Pence, *Trans. A. C. S.*, Vol. XIV, p. 684.

Description of Samples. When drawn at the finish of firing, they all show a distinct gloss. After half an hour, Nos. 3, 4 and 5 show the beginning of matness; after an hour and a half, matness is well developed except in No. 6. When cooled in the kiln, they are all good mats, but No. 6 is shiny along the edges. This, I believe, is due to immaturity. The glaze would be better if burned to a slightly higher temperature. I shall come back to this later. No. 3 was not fired to maturity either, but despite this, it shows the gradual developments of matness very nicely. Particularly interesting in this case is the color change from a brownish green through a bluish green to a black with green patches. To satisfy myself that no accidental reduction had taken place, I repeated this experiment, but the result was the same.

Discussion of Copper Mats. I have had considerable experience in the production of copper-red glazes and of copper lustres. In the first case, the reduction takes place during the firing and extends throughout the glaze; in the second case, the reduction takes place during the cooling and does not extend beyond the surface. I have never observed this mat, black finish due to reoxidation when the reduction took place during the firing, because any reoxidized copper would be redissolved by the fluid glaze. But it may easily be produced if the reduction takes place during the cooling and is stopped at a point where the temperature is still high enough to permit of reoxidation of either the cuprous oxide or the metallic copper, as the case may be. The crinkled surface which result is, to my mind, simply due to the absorption of oxygen by the thin metallic film, which thereby increases in volume. Professor Orton[2] gave this as one possible explanation in the case of Mr. Jackson's gunmetal effect.

I have produced mats of this type in which the crinkled surface was so pronounced that the crinkles could easily be seen by the naked eye. I have gone further than that. By giving a short, strong reduction at a comparatively high temperature, then permitting reoxidation with the resulting crinkled surface, and then reducing again until the temperature was quite low, I was able to produce an iridescent film on top of the crinkled surface.

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[2] *Trans. A. C. S.*, Vol. IX, p. 418.

In the case of mat No. 3, a reduction on cooling was out of the question, as nothing but air passed through the kiln. Therefore, we have, apparently, at this heat treatment, a saturated solution of copper from which the oxide or some other copper compound separated on cooling.

Study of the Effect of Overfire. Now to come back to glaze No. 6. It is well known that any mat glaze may be transformed into a glossy glaze if it is what we usually call "overfired." To show this, I fired all the glazes except No. 1 up to cone 9. The result was as follows: No. 3 was just beginning to run bright, accompanied by boiling. No 6 had also boiled, for it showed a pin-hole effect, but it was still perfectly mat, although owing to the pin holes, it was not so smooth as at the lower temperature. The other three glazes, No. 2, No. 4, and No. 5, were distinctly glossy, but all showed pin holes. These pin holes are apparently due to the "second" boiling to which Mr. Purdy referred in his paper on "Fritted Glazes."[3]

In looking for an explanation of the glossiness in "overfired" mats, the following seemed plausible to me. In the case of a mat glaze in a fluid state, that is, before matness develops, we might assume an emulsion, consisting of different saturated solutions which, on cooling, will crystallize out. If we fire the glaze beyond a certain temperature, the different solutions will become soluble in each other, that is, they will diffuse, forming a homogeneous solution which is not saturated and, therefore, will remain a solution on cooling under ordinary conditions.

Study of Effect of Slow Cooling. Assuming that this was so, I wondered whether it was possible to make this homogeneous solution crystallize on prolonged cooling. To get at this, I refired one set of samples, which I had previously fired to cone 9, to cone 1, taking it that this would practically mean prolonged cooling, that is, taking the burn to the lower cone and the subsequent cooling as one operation. The result was that all of the samples showed more or less of a mat texture, but of a different kind from the one produced by the same glaze at the ordinary heat treatment. The best is No. 5 which came back to a perfect mat.

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[3] *Trans. A. C. S.*, Vol. IX, p. 182.

Conclusions from Experimental Work. The experiments in general show plainly that in all the glazes included in this investigation, matness is due to separation from solution on cooling; and unless we are dealing with an entirely new phenomenon, it appears that these glazes are all crystalline.

OBSERVATIONS ON HIGH-TEMPERATURE MATS

As I included one of the high-temperature mats in this investigation, I will add a few remarks about some observations which I made with this type of mat under commercial conditions, and which, I am sure, cannot be made under ordinary conditions.

For illustration, I will give three formulae:

No. 7.	0.3	K_2O	0.63 Al_2O_3 3.61 SiO_2
	0.7	CaO	O. R. 2.5
No. 8.	0.11	K_2O	0.29 Al_2O_3 2.56 SiO_2
	0.73	CaO	O. R. 2.84
	0.16	MgO	
No. 9.	0.30	K_2O	0.5 Al_2O_3 4.0 SiO_2
	0.35	CaO	O. R. 3.2.
	0.15	MgO	
	0.15	BaO	
	0.05	ZnO	

I have observed a good many more glazes of this type, but these three will suffice for illustration.

These glazes will give good glossy glazes under ordinary conditions even in many commercial kilns, but in the long fire and the necessarily slow cooling of the terra cotta kiln, I produced good mat glazes of different textures with these very formulae. As a matter of fact, one of these glazes was used as a mat glaze on a large scale for several years.

These glazes fall well within that portion of the "bright area" of Professor Stull's chart:[4] in which we could expect mature glazes at cone 7. No. 8 and No. 9 differ from Professor Stull's glazes in the RO content, but No. 7 has the same RO as he used and corresponds almost exactly to his glaze D4.

[4] *Trans. A. C. S.*, Vol. XIV, p. 64.

I observed the same phenomenon with the barium mats under these conditions, but I am not at liberty to give any formulae. I will say, however, that I used oxygen ratios from 2.5 to 3.2, the same as in the above glazes. On quick cooling, these glazes give glossy glazes the same as any other mat glaze which came to my attention. I had one of our students make up a series of barium mats recently, in which he used the same combination of bases which I had used commercially. The samples were burned to cone 7 as usual in about twenty-four hours, and no special precautions were taken on cooling. The result was that he did not find one good mat. The experiment was then repeated, but the burn was prolonged purposely to about fifty hours, and after finishing, the kiln was closed up tight and left to cool as slowly as it possibly would. This time he found some good mat glazes, but not with an oxygen ratio anything above 2, while I had produced good mats with an oxygen ratio as high as 2.9, using the same combination of bases, in a commercial terra cotta kiln.

A HIGH CALCIUM HIGH BARIUM MAT

I had one of our students make up a series of mat glazes recently, in which he used the following combination of bases: CaO, 0.44; BaO, 0.35; K_2O, 0.16; ZnO, 0.05, and varied the alumnina-silica content the same way as Professor Orton did in his experiments on "A Type of Mat Glaze Maturing at Cone 2–4." When the samples came from the kiln, I looked at them with an ordinary hand glass and I thought that I could see some crystals. Thereupon I put the samples under a microscope, and although the crystals were not very distinct, they could easily be seen.

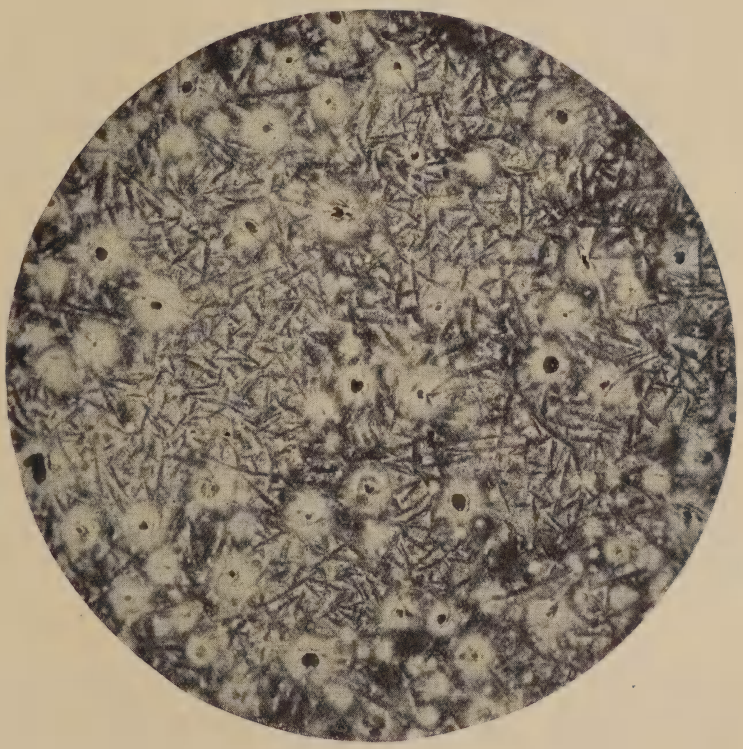
One of the glazes was then selected for color trials. When these were examined under the microscope, it was found that the crystals could be seen much more distinctly, because in most cases the color of the crystals was slightly darker than that of the rest of the glaze. This was particularly pronounced in those glazes which had cobalt as the coloring oxide. In this case the crystals were so distinct even under a low-power microscope that I decided to have a photograph taken for publication in connection with the above discussion on the cause of matness.

The accompanying cut shows the surface of the glaze, as looked

upon from above, magnified but 25 times. It speaks for itself and a detailed explanation seems unnecessary. The photograph was taken by Mr. J. A. Glen of Albany, N. Y.

The formula of this glaze is:

$$\left.\begin{matrix} 0.44 & CaO \\ 0.35 & BaO \\ 0.16 & KO \\ 0.05 & ZnO \end{matrix}\right\} 0.37\ Al_2O_3\ 1.9\ SiO_2$$



It was burned at cone 6, accidentally under slightly reducing conditions, which fact probably accounts for the blisters, which may be seen on the cut. It was colored by an addition of 3 per cent of a stain of the formula CaO, Al_2O_3.

There can hardly be any doubt that crystallization is the cause of matness in this case, but I should like to emphasize the fact that this glaze has the soft finish which is so characteristic of a true mat and it does not take the dirt, as Mr. Purdy claims a crystalline mat would.

GENERAL CONCLUSIONS

My observation, together with these experiments, demonstrates, I think, very nicely the relation which exists between glazes and slags. Professor Orton says in his "Study of a Type of Mat Glaze Maturing at Cone 2–4,"[5] "Basic silicates, in the case of rocks and slags and presumably glazes, also, seem to possess a strong tendency to crystallize in cooling. By increasing the suddenness of their cooling, the glassy structure may still be kept for a time, but in general the more basic the silicate, the more difficult it becomes to get it or hold it in the glassy state on cooling." Applied to glazes, this means that within certain limits, the more basic a glaze is the quicker it may be cooled and the more acid it is the slower it must be cooled in order to produce a mat. In other words, if it was but possible to secure the proper cooling conditions, we ought to be able to make that portion of any glossy glaze crystallize out which is capable of forming definite compounds, whether it would be a good mat texture is, of course, another question.

At any rate, I am convinced that the treatment of a glaze, aside from its composition, plays an important part in the production of mat glazes, and I believe that the characteristics of many commercial mats are due to treatment rather than composition.

DISCUSSION

Prof. Pence: I am very much pleased to see this evidence in support of the theory which I advanced last year. It also demonstrates the fact that evidence pointing to chemical action which takes place in the glaze may be obtained by experiment and observation made in the factory proper. While it may be contended that microscopic observation is essential in affording definite proof,

[5] *Trans. A. C. S.*, Vol. X, p. 575.

the evidence most certainly points to the validity of the theory of crystallization as accounting for the developement of mat texture.

Mr. Purdy: Mr. Chairman, no doubt we have glazes that are mat due to crystalization, but in every crystalline glaze that is mat, the surface is rough. If dirt should be rubbed upon a pure crystalline mat, i.e. completely crystallized, it would remain in the pores of the glaze. The crystals should be very small, the glaze would practically be full. When the crystals are large, the glaze is glossy. The evidence of the tile drawn from a kiln nearly at the finishing heat being glossy whereas it would be mat if allowed to cool in the kiln, is only an illustration of the phenomena of surface tension. You can get a gloss by high surface tension and that is what you produce when you draw the tile out of the kiln hot and allow the outside coat to cool first. Surface tension will produce gloss in these glazes the same as it does in a bristol glaze.

AN INVESTIGATION OF THE SURFACE DEVITRIFICATION OF GLASSES UNDER THERMAL AFTER-TREATMENT

BY C. J. BROCKBANK

INTRODUCTION

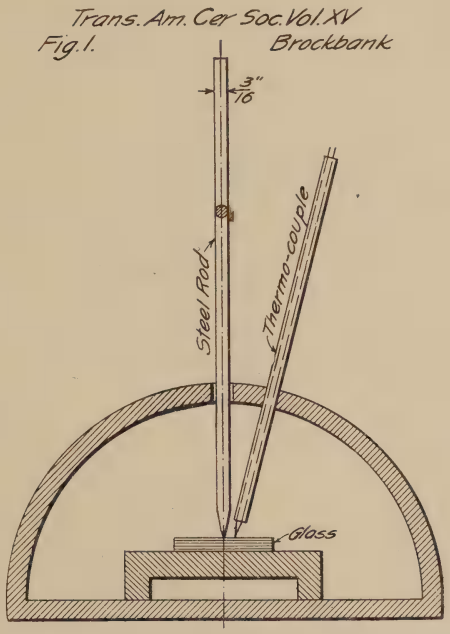
That certain physical and chemical changes take place in the surface layers of some glasses on reheating from the solid to the plastic state, is a fact known to all glass makers. In some glasses the change is so slight as to be barely visible to the naked vision, in other cases it will progress to such an extent as to cause a frosted appearance and entire loss of brilliancy. Under the microscope such a speciman will show numerous small spheres of typically devitrified material. This defect is undoubtedly produced by the volatization of potassium or sodium oxide from the glass, and the consequent production in the surface layer of a silicate containing a very high percentage of SiO_2. It is interesting to note that this change will progress entirely through a solid piece of glass if it is maintained at the critical temperature for a period of several days.

EXPERIMENTAL WORK

That the susceptibility of a class to this change is intimately related to its chemical composition has long been recognized; but, so far as the writer is aware, this relationship has never been made the subject of special investigation. This paper is a description of experiments having as their object: (1) The determination of the influence of the chemical composition of a glass on its susceptibility to this defect. (2) The critical temperature required to induce such changes with reasonable rapidity. Since the soda-lime-silicates exhibit this defect more often than other types, the investigation was limited mainly to this type, the effect of various additives also being studied.

Two series of meltings were made as shown in Table I, the first series of seventeen meltings on a laboratory scale, the second series consisting of six full size factory melts of fifteen hundred pounds. For the laboratory melts, a gas furnace, capable of melting about

five pounds of material, was used. The temperature toward the end of the heating probably reached 1600°C. The cooling usually occupied twelve hours, and the block of glass could then be extracted from the pot in one or two large pieces. From these pieces, small test plates, 1 inch by 1 inch by $\frac{1}{8}$ inch, were ground, polished and used for the experiments. The refractive index of each plate for the D line of the spectrum was first determined. This value, of course, has no significance in connection with the thermal changes; but it



involved very little extra trouble, and opens up an interesting side line which will be investigated later.

The heat treatment consisted in the determination of two points: (1) The temperature at which softening could be detected. (2) The temperature at which surface dimming was first observed. These will hereafter be called the softening and dimming points.

A gas muffle furnace of the ordinary type, fitted with a mica door, was used for these tests, suitable provision being made for

TABLE 1—SERIES 1

Group I. Melts of Five Pounds

No. of glass	1	2	3	4	5
n/D	1.510	1.502	1.496	1.508	1.508
Softening point	1350°	1450°	1300°	1350°	1300°
Dimming point	1400°	1500°	1525°	1525°	1350°
Sand	633	679	636	640	654
Pearl ash (dry)		204			
Potass: nitrate	28	30	32	32	32
Arsenious oxide	4	4	4	4	4
Soda ash	176		223	223	230
Slaked lime	69	83		78	80
Borax	68				
Magnesium carbonate			105		
Aluminium hydrate				20	

Group II. Melts of Five Pounds

No. of glass	6	7	8	9	10	11
n/D	1.506	1.511	1.508	1.511	1.515	1.512
Softening point	1300°	1300° 1325°	1300°	1325°	1300°	1300°
Dimming point	1450° 1475°	1475° 1500°	1475°	1550°	1600°	above 1600°
Sand	633	612	617	597	576	603
Potass: nitrate	32					
Arsenious oxide	4	4	4	4	4	4
Soda ash	221	214	216	209	203	212
Sod: nitrate		30	31	30	30	30
Slaked lime	58	74				
Magnesium carbonate	52	66			37	
Aluminium hydrate						21
Dolomite			132	160	150	

Group III. Melts of Five Pounds

No. of glass	12	13	14
n/D	1.512	1.511	1.505
Softening point	1300°	1325°	1300°
Dimming point	1500°	1500°	1450°
Sand		627	631
Arsenious oxide		4	4
Soda ash		203	222
Sodium nitrate		31	33
Slaked lime			58
Magnesium carbonate			52
Dolomite		135	

Group IV. Melts of Five Pounds

No. of glass	15	16	17
n/D	1.615	1.597	1.615
Softening point	1250°	1200°	1150°
Dimming point	1350°	1300°	1250°
Sand	432	420	428
Pearl ash	81		
Red lead	466	460	462
Potass: nitrate	19		10
Arsenious oxide	2	2	2
Soda ash		96	47
Sodium nitrate		22	10

SERIES 2
Melts of 1500 Pounds

No. of melt	1	2	3	4	5	6
n/D	1.516	1.505	1.507	1.511	1.5075	1.506
Dimming point	1400°	1500°	1550° 1575°	1500°	1525°	1450°
Sand	597	648	640	638	643	590
Potass: carbonate		179				
Soda ash	172		224	223	235	225
Slaked lime	81	70	77		67	
Nitrate of soda	27	29	32	32	32	
Arsenious oxide	4	4	4	4	4	2
Borax	119	70				
Boric acid			23			
Aluminium hydrate				103		
Slaked dolomite					29	
Calcined MgO						
Potass: nitrate						46
Chalk						39

the introduction of a thermo-couple through the wall of the muffle and of a small, pointed, steel rod, $\frac{3}{16}$ inches in diameter and 1 inch long. The polished section of the glass to be tested was raised from the floor of the muffle on a small fire-clay bridge. The muffle was started from the cold, and the softening point and dimming point determined by means of the pointed steel rod and the thermo-couple. The general arrangement of the apparatus is shown in Figure 1. The steel point was allowed to rest of its own weight on

the polished surface of the glass. The softening temperature was immediately manifested by the distortion of the reflections of the steel point and the thermo-couple. These reflections were quite brilliant under the conditions obtaining, and no difficulty was experienced in checking results very closely. The dimming point also was indicated by the disappearance of these reflections. This surface clouding takes place quite suddenly when the critical temperature is reached, and can be checked + or − 10° in different plates from the same melting. Since the time taken in heating the test plates has some influence on the temperature at which devitrification commences, every precaution possible was taken to maintain a constant gas pressure, and the time spent in attaining a given temperature was checked in each experiment.

The materials used were of the ordinary grade used in glass mixtures, and were fairly pure. The slaked lime was the most impure, an average analysis giving:

	percent		*percent*
$Ca(OH)_2$	92.48	Al_2O_3	0.86
$CaCO_3$	3.14	MgO	0.31
CaO	0.31	SiO_2	0.41
Fe_2O_3	0.21	H_2O	2.20

All the mixtures given are figured in parts per thousand, the temperatures in Fahrenheit degrees.

DISCUSSION OF RESULTS

Group 1. Comparing 2 with 5 we notice that the substitution of potassium carbonate for sodium carbonate raises the dimming point 200° and greatly increases chemical and physical stability.

In 3 we have the effect of substituting magnesia for lime. The effect is peculiar in as much as the dimming point is raised from 1350° to 1525°, the softening point remaining the same.

Number 4 shows that the addition of alumina is beneficial. Number 1 indicates that the use of boric acid will not give very marked improvement.

Group 2. Numbers 8, 9, 10 and 11 show that the use of the double carbonate of calcium and magnesium in the form of dolomite is markedly beneficial, particularly in conjunction with a little

alumina. Number 11 was the most stable of any glass tested. Also notice that this small addition of alumina does not raise the softening point; it has, however, one disadvantage, that the glass is more difficult to "fine."

Group 3. These are practically checks on the previous mixtures.

Group 4. These are flint glasses. They do not devitrify in the same way as the crowns, but simply take on a frosted appearance, the action then practically ceasing. The substitution of soda for potash is detrimental, and the use of mixture of these two still more so.

Series 2. These mixtures were meltings on a commercial scale in covered pots and were based on the smaller trials made in the laboratory. The value of introducing alumina and magnesia is fully sustained, and the conclusion based on the laboratory trials confirmed, in other material respects. The glasses of this series were blown into sheets in the usual way, No. 6 especially giving excellent results.

CONCLUSION

Summarising, it can be stated that the introduction of magnesia, and particularly alumina into white sheet glass is of great benefit, making the glass more stable.

The use of dolomic limestone is markedly beneficial, contrary to the view held by many glass makers. It is a custom in Europe to add alumina in some form to tank glass, usually to the extent of two percent. The reason generally given for this procedure is that such a glass is less likely to attack the fireclay blocks of which the tank is built, and that, therefore, clay stones will not be so prevalent in the "metal." It is much more likely that devitrification stones are less prevalent, and that these have been confused with clay-stones. The writer's experience in adding alumina to special glasses which attacked clay pots at a remarkable rate gave negative results. The alumina did, however, greatly increase the viscosity of such glasses when present in amounts above 3 percent.

THE DEVELOPMENT OF SPECIAL REFRACTORY BODIES[1]

BY E. T. MONTGOMERY, BUREAU OF STANDARDS

While there have been but few absolutely new refractory materials developed in the past few years, the pressing needs of the rapidly developing chemical, metallurgical, electrical and ceramic industries in the way of suitable refractories, have stimulated some truly remarkable developments in the preparation of refractory materials from the old and well known raw materials, and in the compounding and manufacture from these materials, of refractory bodies for special purposes.

Object of the Work. The data to be discussed in this paper are the results obtained in a study of refractory bodies suitable for pyrometer tubes in particular, or for any product in which similar properties are required.

Requirements of the Body. A body suitable for pyrometer tubes must meet the following requirements:

1. It must be as refractory as possible, having a fusion point above cone 30 unless the tube is for low temperature work only.
2. It must stand sudden and repeated changes of temperature without rupture.
3. It must be either impervious to gases without a glaze or such a body that it can be glazed or otherwise rendered impervious.
4. It must not warp or deform within the temperature range in which the tubes are to be used.
5. It should preferably be a body which is plastic enough to be used in a tube machine forming the tubes through a die.

Compositions Tested. In deciding on the different series of body compositions to include in the investigations, I was guided by a consideration of the composition of German and American pyrometer tubes now on the market about which some information was available, and by previous consulting experience in the development of a suitable body for gas mantle rings.

In German *Handbuch der gesammten Thonwaarenindustrie*, the Marquart tube as made in 1907 was reported to be composed of

[1] By permission of the Director of the Bureau of Standards.

70 percent grog (made up of 60 percent Rackonitz shale kaolin and 10 percent Al_2O_3) and 30 percent ball clay. This body was fired to cone 20. Since 1907 the Marquart tube has been improved but the new composition has not been reported so far as I can learn. Analyses of the Marquart inner and outer tubes now on the market were made by Mr. A. J. Phillips, chemist at the Pittsburgh Laboratory of the Bureau of Standards, with the following results:

	INNER TUBE	OUTER TUBE
SiO_2	34.89	29.75
Al_2O_3	59.47	66.52
Fe_2O_3	0.96	0.65
TiO_2	0.62	0.43
CaO	0.85	0.66
MgO	0.10	0.26
Na_2O	0.79	0.70
K_2O	0.57	0.92
H_2O (on ignition)	1.89	0.31
	100.14	100.20

These analyses indicate that the Al_2O_3 content has been increased in the Marquart tube grog, and that a higher content of Al_2O_3 is used in the outer tube than in the inner tube. Calculating the composition from these analyses we see that the inner tube contains about 30 percent calcined Al_2O_3 and 70 percent clay part of which is also calcined, probably about 40 percent leaving 30 percent to be added as raw ball clay as in the original Marquart tube body; and that the outer tube contains about 40 percent calcined Al_2O_3 and 60 percent clay of which probably 30 percent is calcined, leaving as before 30 percent ball clay to give plasticity to the body and to act as the bond in firing. The only American tube about which I secured any information was the Norton Company's tube composed of bonded "Alundum" (fused Al_2O_3).

It was not my purpose to try to duplicate any tube on the market, but to make a study of the technical difficulties involved, the peculiar properties, whether physical or chemical, of bodies which will meet the unusual requirements or a pyrometer tube body, and

to discover if possible the value or uselessness of the ordinary refractory materials at our command for use in compounding such bodies. I was particularly interested in developing a high magnesia tube as the value of magnesia in bodies to withstand sudden temperature changes has already been demonstrated.

The four following series were therefore outlined. All bodies were designed to be plastic enough to work through a tube machine, and either all bodies of a series were designed to be refractory or refractoriness was to be developed in the higher members of the series:

Series "A" was designed to test the value of fused magnesite bonded and made workable by clay additions.

Series "B" was designed to test the value of calcined Al_2O_3. Series "C" was designed to test the value of calcined kaolin.

Series "D" is composed of miscellaneous bodies. 1 D was to show the effect of replacing the 70 percent North Carolina kaolin in 1 C by Georgia kaolin. 2 D was to show the relative values of calcined flint and calcined kaolin as compared with 1 D. 3 D was designed from a gas mantle ring analysis and brings in 12 percent MgO. 4 D was to show the value of an addition of spar to a calcined Al_2O_3 body.

Materials Used. The fused magnesite was obtained from the Electrical Engineering Department of the University of Illinois. It was received in a powdered condition, none of the particles being larger than about 20-mesh. The calcined alumina was the ordinary commercial Al_2O_3 calcined at cone 12. The calcined North Carolina kaolin and flint was also calcined at cone 12. The clays used were English ball, Georgia kaolin and Dillsboro, North Carolina kaolin.

Preparation of the Bodies. The bodies were weighed out and ground in ball mills until the slip would pass a 100-mesh lawn. The water was removed from the slip by means of filter sacks and the bodies thoroughly wedged by hand.

Making the Tubes. The tubes were all formed on a piston tube machine designed and built at the Pittsburgh Laboratories. They were removed from the machine on grooved ware boards, carefully dried and cut into lengths suitable for the different tests devised for them.

A OR MgO SERIES	B OR Al_2O_3 SERIES	C OR CLAY SERIES	D OR MISC. SERIES
OA: 30 English ball; 55 Georgia kaolin; 15 Fused MgO	OB: 15 English ball; 70 Georgia kaolin; 15 Calcined Al_2O_3	1C: 15 English ball; 70 North Carolina kaolin; 15 Calcined North Carolina kaolin	1D: 15 English ball; 70 Georgia kaolin; 15 Calcined North Carolina kaolin
1A: 30 English ball; 40 Georgia kaolin; 30 Fused MgO	1B: 15 English ball; 55 Georgia kaolin; 30 Calcined Al_2O_3	2C: 15 English ball; 55 North Carolina kaolin; 30 Calcined North Carolina kaolin	2D: 15 English ball; 70 Georgia kaolin; 15 Calcined flint
$1\frac{1}{2}$A: 30 English ball; 30 Georgia kaolin; 40 Fused MgO	2B: 15 English ball; 35 Georgia kaolin; 50 Calcined Al_2O_3	3C: 15 English ball; 35 North Carolina kaolin; 50 Calcined North Carolina kaolin	3D: 15 English ball; 59 Georgia kaolin; 12 Fused MgO; 14 Calcined flint
2A: 30 English ball; 20 Georgia kaolin; 50 Fused MgO	3B: 15 English ball; 15 Georgia kaolin; 70 Calcined Al_2O_3		4D: 15 English ball; 45 Georgia kaolin; 30 Calcined Al_2O_3; 10 Feldspar
3A: 30 English ball; 70 Fused MgO			
4A: 20 English ball; 80 Fused MgO			

Burning the Tubes. In burning the tubes two firing temperatures were used—cone 12 and cone 18. All of the tubes were fired in saggers. At cone 12 the MgO tubes were bedded in calcined kaolin while the rest were bedded in white sand. At cone 18 the MgO tubes were bedded in pulverized fused MgO and the others in calcined Al_2O_3.

Testing the Tubes. Tests were devised to show clearly whether or not the bodies would meet the requirements set forth above as being the necessary requisites of a satisfactory tube body.

1. Refractoriness. Cones were made up from each body and the cone of fusion determined in an electric furnace.

2. Resistance to Sudden Temperature Changes. Pieces of tubes about 4 inches to 5 inches were heated to 900°C. in an electric furnace, removed and immediately placed in a heavy blast of cold air so that the air would blow against one side of the tube. In this test the outside of the tube and especially the portion on which the blast was directly blowing would become black very rapidly while the inside of the tube was still red hot. This is a very severe test and much more intensive than dropping the red hot tube into cold water or even partially immersing it in water. Those tubes which cracked in the cold air blast test were further tested by cooling other samples heated to 900°C. in air at room temperature and also by partial immersion in water.

3. Imperviousness to Gases Without a Glaze or Slip. This was tested by making absorption tests in water. The samples were soaked three hours in water in a vacuum corresponding to 29 inches of mercury. This test also shows the relative density of structure of the bodies at the two firing temperatures and also as compared with each other in a given series. This is important as the density of structure has a marked effect on the ability of a body to stand the sudden heating and cooling test.

4. Warpage or Deformation. This was tested by placing 12-inch lengths of tube in the kiln, set in a horizontal position on knife edges to span 10 inches and then firing them to cone 12.

Fire shrinkage was measured by marking the dry tubes for shrinkage measurement before they went into the kiln. No measurement of drying shrinkage was attempted as the different bodies had to be worked at varying degrees of stiffness.

Results of Tests. In giving and discussing the results of these tests, let us first fix the standard by which any pyrometer tube body must be judged. In a problem of this kind such a standard is set by the requirements which such a body should meet and by the success with which tubes now on the market meet these requirements. Mere refractoriness is easy to obtain and by virtue of its refractoriness a body has naturally in a high degree, ability to stand high temperature without warping. Imperviousness to gases is obtained by the use of a glaze or slip which seals the pore system on the surface of the tube. As a final criterion then, a tube body must stand or fall by its ability to withstand sudden heating and cooling, for by this property is not only its liability to accident measured but also the life of the tube in active service.

Of the tubes now on the market only the two previously mentioned were tested, as representative of the best German and the best American made tubes. The sample of Marquart tube tested was taken from the regular tube supply purchased by our laboratory. It is as you will remember a high Al_2O_3 tube. It is glazed with a refractory glaze to make it impervious. The sample tested had an absorption of 13.7 percent in terms of dry weight. Two samples of this tube tested in the air blast test behaved similarly. They stood one heating and cooling from 900°C. to cold air blast safely but immediately fell into a dozen or more pieces upon replacing in the furnace at 900° for a second test.

The sample of Norton pyrometer tube tested was furnished me for this purpose through the courtesy of the Research Department of the Norton Company. It is a bonded "Alundum" tube made impervious to gases by a refractory slip or glaze to seal the outside pores. The sample tested had an absorption of 13 percent in terms of dry weight. Samples of this tube tested in the air blast test, as above described, stood ten repeated tests without a rupture of any kind.

The results of the tests on the four series of bodies covered by this paper are shown in the following tables:

TABLE 1—PROPERTIES OF RAW TUBES

MARK	COMPOSITION	WORKING PROPERTIES	DRYING BEHAVIOR	REMARKS ON BODY
OA	30 English ball 55 Georgia kaolin 15 Fused MgO	Very plastic. Fine through die	Dried safely. No warping	Makes fine straight tube
1A	30 English ball 40 Georgia kaolin 30 Fused MgO	Good plasticity. Well through die	Dried safely. No warping	Makes fine straight tube
$1\frac{1}{2}$A	30 English ball 30 Georgia kaolin 40 Fused MgO	Good plasticity. Well through die	Dried safely. No warping	Makes fine straight tube
2A	30 English ball 20 Georgia kaolin 50 Fused MgO	Good plasticity. Well through die	Dried safely. No warping	Makes fine straight tube
3A	30 English ball 70 Fused MgO	Good plasticity. Well through die	Dried safely. No warping	Makes fine straight tube
4A	20 English ball 80 Fused MgO	Rather short. Difficult through die	Some cracking on fast drying. No warping	Body must be dried slowly and carefully
OB	15 English ball 70 Georgia kaolin 15 Calcined Al_2O_3	Very plastic. Fine through die	Dried safely. No warping	Makes fine straight tube
1B	15 English ball 55 Georgia kaolin 30 Calcined Al_2O_3	Very plastic. Fine through die	Dried safely. No warping	Makes fine straight tube
2B	15 English ball 35 Georgia kaolin 50 Calcined Al_2O_3	Very plastic. Fine through die	Dried safely. No warping	Makes fine straight tube

3B	15 English ball 15 Georgia kaolin 70 Calcined Al_2O_3	Good plasticity. Well through die.	Some cracking on fast drying. No warping.	Makes fine straight tube
1C	15 English ball 70 North Carolina kaolin 15 Calcined North Carolina kaolin	Fair plasticity. Well through die	Dried safely. No warping	Dry tube rather brittle, difficult to eliminate flaws
2C	15 English ball 55 North Carolina kaolin 30 Calcined North Carolina kaolin	Rather short. Fair through die	Some cracking. No warping	Dry tube rather brittle, difficult to eliminate flaws
3C	15 English ball 35 North Carolina kaolin 50 Calcined North Carolina kaolin	Very short. Very difficult through die	Cracking. No warping	Body very short, much cracking. Dry tube, weak and brittle. Many flaws
1D	15 English ball 70 Georgia kaolin 15 Calcined North Carolina kaolin	Very plastic. Fine through die.	Dried safely. No warping	Fine straight tube
2D	15 English ball 70 Georgia kaolin 15 Calcined flint	Very plastic. Fine through die	Dried safely. No warping	Fine straight tube
3D	15 English ball 59 Georgia kaolin 12 Fused MgO 14 Calcined flint	Good plasticity. Well through die	Dried safely. No warping	Fine straight tube
4D	15 English ball 45 Georgia kaolin 30 Calcined Al_2O_3 10 Feldspar	Good plasticity. through die	Dried safely. No warping	Fine straight tube

TABLE 2. PROPERTIES OF TUBES AT CONE 12

MARK	FIRE SHRINKAGE	HARDNESS	COLOR	CONDITION OF BODY	ABSORPTION IN TERMS OF DRY WEIGHT	WARPAGE TEST	SUDDEN COOLING TEST		
							Air in room	Water ½ in ½ out	Air Blast
	percent				*percent*				
0A	12.0	Steel hard	Gray	Fine straight tube	0.25	No warping	Safe	Safe	Safe (10 tests)
1A	9.0	Steel hard	Light yellow	Fine straight tube	9.4	No warping	Safe	Safe	Safe (10 tests)
1½A	6.0	Steel hard	Light yellow	Fine straight tube	11.8	Not tested	Safe	Safe	Safe (10 tests)
2A	4.0	Steel hard	Light yellow	Fine straight tube	20.0	No warping	Safe	Safe	Safe (10 tests)
3A	0	Cuts quite easily	Cream white	Fine straight tube. Body not dense	23.4	No warping	Safe	Safe	Body not dense enough, cracked
4A	0	Cuts quite easily	Cream white	Fine straight tube. Body not dense	24.6	No warping	Safe	Safe	Body not dense enough, cracked
0B	9.0	Steel hard	White	Fine smooth straight tube	13.2	No warping	Safe	Safe	Stood 1 test, cracked on second
1B	7.0	Difficult to scratch with knife	White	Fine smooth straight tube	18.9	No warping	Safe	Safe	Cracked

2B	3.5	Will scratch with knife	White	Fine smooth straight tube	28.0	No warping	Safe	Safe	Cracked
3B	3.0	Scratches quite easily	White	Fine smooth straight tube	35.0	No warping	Safe	Safe	Cracked
1C	5.0	Difficult to scratch	White	Good straight tube	21.4	No warping	Safe	Safe	Stood 1 test, cracked on second
2C	3.5	Difficult to scratch	White	Good straight tube	24.2	No warping	Safe	Safe	Cracked
3C	2.5	Scratches quite easily	White	Fair body, tube straight	28.9	No warping	Safe	Safe	Cracked
1D	8.0	Steel hard	White	Fine straight tube	11.6	No warping	Safe	Safe	Cracked
2D	7.5	Steel hard	White	Fine straight tube	11.8	No warping	Safe	Safe	Cracked
3D	7.5	Very difficult to scratch	White	Fine straight tube	19.6	No warping	Safe	Safe	Stood 6 tests
4D	7.0	Very difficult to scratch	White	Fine straight tube	16.7	No warping	Safe	Safe	Cracked

TABLE 3—PROPERTIES OF TUBES AT CONE 18

MARK	FIRE SHRINKAGE	HARDNESS	COLOR	CONDITION OF BODY	ABSORPTION IN TERMS OF DRY WEIGHT	SUDDEN COOLING TEST. AIR BLAST	CONE OF FUSION. QUICK HEATING
	percent				*percent*		
OA							16
1A							14
1½A							12
2A	4	Steel hard	Light yellow	Fine straight tube	15.0	Safe (10 tests)	32
3A	0	Difficult to scratch	Light yellow	Fine straight tube	19.6	Safe (10 tests)	Above 32
4A	0	Difficult to scratch	Light yellow	Fine straight tube	20.2	Safe (10 tests)	Above 32
0B	11	Steel hard	White	Fine straight tube	7.9	Cracked. Too hard	Above 32
1B	7	Difficult to scratch	White	Fine straight tube	17.7	Cracked. Too hard	Above 32
2B	3	Difficult to scratch	White	Fine straight tube	25.0	Cracked. Too hard	Above 32
3B	3	Difficult to scratch	White	Fine straight tube	30.0	Stood 7 tests	Above 32
1C	10	Steel hard	White	Good straight tube	6.4	Cracked	Above 32
2C	8	Steel hard	White	Good straight tube	10.0	Cracked	Above 32
3C	7	Steel hard	White	Good straight tube	16.4	Stood 6 tests	Above 32
1D	11	Steel hard	White	Fine dense straight tube	1.2	Cracked	Above 32
2D	11	Steel hard	White	Fine dense straight tube	4.0	Cracked	Above 32
3D				Tube fused			16
4D	8	Steel hard	White	Tube fused	11.7	Cracked	Above 32

Discussion of Results. *MgO Series.* This whole series shows very satisfactory results, all members standing the sudden cooling test perfectly when fired to the proper maturing temperature. Any desired degree of refractoriness is developed. These tubes I have rendered impervious by the use of a properly constituted slip or engobe. I have used for this purpose a slip of body OA on the higher members of the series. They have a high thermal conductivity and low coefficient of expansion, also high mechanical strength. Magnesium oxide has also a beneficial rather than a detrimental effect on the platinum thermocouple elements.

I wish to make particular mention of body OA for low temperature work up to cone 12. This body besides standing the sudden cooling test is practically non-absorbent, fired at cone 12, and would be impervious to gases without a glaze or slip.

There is one precaution which would have to be observed in the use of MgO tubes, especially at high temperatures, and that is to support the tube when in use on magnesite brick.

Al_2O_3 Series. This series developed tubes similar to the Marquart tube. These tubes stood sudden changes of temperature not by virtue of high thermal conductivity and low coefficient of expansion but by virtue of an open, porous body of proper density developed by the proper firing temperature. If too hard and too dense, they crack, and if too soft and punky, they also crack. Body OB at cone 12 developed a density which permitted it to stand one heating and cooling test and body 3 B at cone 18 developed a density which allowed it to stand 7 repeated tests before it cracked. Bodies 1 B and 2 B undoubtedly developed similar densities of structure at intermediate temperatures. These bodies are all highly refractory, could be glazed, and make a fine, white, smooth tube of about the quality of the Marquart tube.

Clay Series. The same remarks apply to this series as to the Al_2O_3 series, except that the working qualities of the bodies were not so good. Georgia kaolin substituted for the uncalcined North Carolina kaolin in the series would have made much better working bodies, but would have also changed the densities of structure and therefore in all probability would have shifted the sudden cooling tests somewhat. As the series stands, body 1 C at cone 12 stood 1 test and body 3 C at cone 18 stood 6 sudden cooling tests before cracking.

Miscellaneous Series. This series developed one body, 3 D, at cone 12 which was quite satisfactory for a low temperature tube. Different samples stood from 5 to 6 repeated heating and cooling tests in the air blast before cracking. This body, however, is not refractory, fusing at about cone 16.

General Conclusions. In conclusion we may say in general that pyrometer tube bodies are of two classes: (1) refractory bodies which stand sudden changes of temperature by virtue of the properties of high thermal conductivity and low coefficient of expansion inherent in their constitutents, and (2) refractory bodies of an open, porous structure but of just the proper density to admit of the ingress and egress of heat with the least detrimental results to the body.

Refractory materials from which pyrometer tubes of the first class are made are the best and safest. These include fused magnesite, fused alumina and fused quartz.

Pyrometer tubes of the second class may be made from combinations of calcined and uncalcined Al_2O_3, kaolins and ball clays, but are of an inferior quality.

DISCUSSION

Dr. Sosman: I would like to ask what is the composition of OA?

Mr. Montgomery: 15 magnesia, 55 Georgia kaolin and 30 English ball clay.

Prof. Parmelee: What was the temperature of the cold blast?

Mr. Montgomery: I cannot tell you the exact temperature; it would vary somewhat. It was the air supplied by the compressor and would be practically room temperature.

Mr. Frink: I have used fused MgO and have a little experience that may be worth mentioning. We made two or three hundred tubes, and used a composition something like that OA, substituting for the Georgia clay a little kaolin, 21 or 22 parts of the Georgia kaolin for the Georgia clay. We had a tube we couldn't do very much with under certain conditions, those conditions being in brick kilns and hollow ware kilns, where they were burning coal. I don't know exactly what the effect is, but apparently phosphorus has something to do with it; that is, we found on analysis that at the ends of these tubes there was found phosphorus. It comes

from the coal or somewhere. The tubes become quite porous to the gases and other elements deteriorated very rapidly, and we have gone back to our old tubes.

Prof. Stull: I wish to make a correction. The MgO_3 used, when commercially prepared, is considered very pure. It is fused into a beautiful crystalline glass-like substance and used in that form. I might add that the cost, not including the cost of the $MgCO_3$ was $2\frac{1}{2}$ cents a pound. I think it costs on the market 20 cents a pound. You can buy the raw material for $2\frac{1}{2}$ cents to $3\frac{1}{2}$ cents; adding $2\frac{1}{2}$ cents to that, makes the total cost about 5 cents a pound. The cost, including the cost of current at city rates, was the cost of carbides; it didn't include time; time is not counted.

Dr. Parsons: There is one of our industries that requires pyrometer tubes, if they are going to make certain improvements; they are very anxious to find out about that. They need another physical characteristic, namely, that the tube shall have a specially good heat conductivity, so there may be a very slight lag in making the measurement in case of brass foundries and general non-ferrous alloys. I should like to know from Mr. Montgomery whether or not he made such tests on these pyrometer tubes, and especially whether or not he has made tests with other oxides like zirconium or cerium oxide for tubes of this character? They can now be obtained very cheaply, the zirconium oxide can be obtained more cheaply than the oxide of which Professor Stull spoke.

Mr. Montgomery: I would say that I have not, so far, been able to carry on a number of suggested researches to continue this in the same line of work. I have not tried the other oxides mentioned and have not made any conductivity tests on the magnesite tubes. We know that magnesite brick is a brick of high thermo-conductivity. Just in a general way I know that fused magnesia has a high conductivity as has used alumina, but I have so far made no measurements or tests to cover that point, but hope to do so as the work continues. We are not through with it yet.

LEADLESS ENAMELS

BY HOMER F. STALEY AND GEORGE P. FISHER, OHIO STATE UNIVERSITY

INTRODUCTION

The object of this investigation was to produce enamels for cast iron free from lead. There is a demand for such enamels; first, because they are specified for use in hospitals and other places by certain architects who fear that enamels containing lead might be poisonous; second, because enamels in which lead is replaced by other fluxes are sought by manufacturers in order to make possible the elimination of lead poisoning from among the workmen in enameling plants.

EXPERIMENTAL WORK

Outline of Investigation. It was decided to approach the problem in two lines of attack:

I. The elimination of lead oxide from a commercial cast iron enamel.

II. The conversion of a sheet steel enamel (free from lead oxide) into an enamel that would work satisfactorily on cast iron.

Method of Calculation. In this investigation no use was made of empirical formulae; but all calculations were based on the method of melted weights and fusibility factors described in "The Control of Fusibility in Enamels," by Homer F. Staley, Trans. Amer. Cer. Soc., Vol. XIII, p. 502. This method was adopted because it gave an easy and convenient means of keeping the fusibility of all the enamels in the series practically uniform with that of commercial cast iron enamels.

Method of Preparing the Enamels. Since it is not possible to get the same results by blending enamels as in enamels of the same composition melted separately, each enamel in all the series of this investigation was weighed out and melted separately in a gas-fired pot furnace. The fire was kept thoroughly oxidizing during the fritting process. The fritted enamels were tapped off into cold water, dried and finely ground.

Testing of Enamels. The enamels were applied by the dry process to small cast iron trials. The ground coat used was a good coat secured from an enameling plant in successful operation. The furnace used for heating the trials was a small gas-fired muffle in which oxidizing conditions were easily maintained.

PART I

THE ELIMINATION OF LEAD OXIDE FROM A COMMERCIAL CAST IRON ENAMEL

As a basis for this part of the work, the commercial cast iron enamel designated as A 1 in Table I was taken.

SERIES I

THE REPLACEMENT OF LEAD OXIDE BY ZINC OXIDE

This series was designated to replace as much lead oxide as possible by zinc oxide; but as it was not thought advisable, on account of the danger of dull finish due to crystallization, to go above 150 pounds of ZnO to 1,000 pounds of melted enamel, the last portion of lead oxide was replaced by barium oxide. Since, according to Staley, as cited above, lead oxide and zinc oxide have (when used in moderate amounts) the same fluxing power, pound for pound, in enamels, the substitutions were made on this basis. The three members of this series are given in Table 1.

Description of the Trials. All enamels of this series had a good gloss, color, and were free from crazing.

SERIES II

REPLACEMENT OF ZINC OXIDE BY CALCIUM FLUORIDE AND FELDSPAR

In this series calcium fluoride and feldspar were blended in the ratio of four parts by weight of fluorspar to one part of feldspar. The mixture was then substituted, pound for pound, for the zinc oxide. It had previously been found by experiment that such a substitution in small amounts did not alter the fusibility of the enamel. Incidentally, in order to render the recipe more simple, the 15 pounds of CaO were replaced by an equal amount of Na_2O from soda ash The members of this series are shown in Table II.

TABLE I

	A 1		A 2		A 3	
	Melted	Raw	Melted	Raw	Melted	Raw
Feldspar*	422.0	422.0	422.0	422.0	422.0	422.0
CaF_2	122.5	122.5	122.5	122.5	122.5	122.5
Borax	80.0	151.0	80.0	151.0	80.0	151.0
Na_2CO_3	47.0	80.84	47.0	80.84	47.0	80.84
$NaNO_3$	10.0	27.4	10.0	27.4	10.0	27.4
$BaCO_3$	10.0	12.9	30.0	38.7	70.0	90.3
$CaCO_3$	15.0	26.85	15.0	26.85	15.0	26.85
ZnO	50.0	50.0	150.0	150.0	150.0	150.0
Pb_3O_4	160.0	163.0	40.0	40.8	.....	.....
SnO_2	83.0	83.0	83.0	83.0	83.0	83.0
	999.5		999.5		999.5	

* The feldspar used in this investigation was Canadian feldspar of the following analysis:

SiO_2	65.15
Al_2O_3	18.65
Fe_2O_3	0.10
CaO	0.18
K_2O	10.88
Na_2O	4.44
H_2O	0.32
	99.72

TABLE II

	A 3		B 1		B 2		B 3	
	Melted	Raw	Melted	Raw	Melted	Raw	Melted	Raw
Feldspar	422.0	422.0	430.0	430.0	438.0	438.0	452.0	452.0
CaF_2	122.5	122.5	154.5	154.5	186.0	186.0	242.5	242.5
Borax	80.0	151.0	80.0	151.0	80.0	151.0	80.0	151.0
Na_2CO_3	47.0	80.84	62.0	107.0	62.0	107.0	62.0	107.0
$NaNO_3$	10.0	27.4	10.0	27.4	10.0	27.4	10.0	27.4
$BaCO_3$	70.0	90.3	70.0	90.3	70.0	90.3	70.0	90.3
$CaCO_3$	15.0	26.85	.....	.....	.....	.....	.....	.....
ZnO	150.0	150.0	110.0	110.0	70.0	70.0	.....	.....
Pb_3O_4	.....	.....	.....	.....	.....	.....	.....	.....
SnO_2	83.0	83.0	83.0	83.0	83.0	83.0	83.0	83.0
	999.5		999.5		999.0		999.5	

Description of the Trials. All the enamels of this series, with the exception of B 3, had good gloss and color. In B 3 the color was good but the gloss had deteriorated somewhat. There was crazing in B 2 and B 3. In commercial practice, it would probably not be advisable to go higher in CaF_2 than the amount shown in B 1.

CONCLUSIONS FOR PART I

In this part of the investigation, two good, glossy, leadless enamels free from crazing have been produced. These are those designated as A 3 and B 1.

PART II

THE CONVERSION OF A SHEET STEEL ENAMEL (FREE FROM LEAD AND ZINC OXIDES) INTO A CAST IRON ENAMEL

As a basis for this part of the investigation, a good commercial sheet steel enamel was taken. This is shown in Series III, C 1.

SERIES III

INCREASE IN FUSIBILITY AND DECREASE OF FLUORIDES

This series was designated to increase the fusibility of the sheet steel enamel and then to reduce the percentage of fluorides by replacing, pound for pound, a mixture of fluorspar and feldspar, in a proportion of four to one, by sodium oxide from sodium carbonate. This substitution had been found by experiment not to affect the fusibility of the enamel. The "Fusibility Ratio"[1] of C 1 was found to be 1.5 : 1. The "Fusibility Ratio" of cast iron enamels runs about 2.1 : 1. In order to bring the fusibility of C 1 to this ratio, the following changes were made in the composition. The 268 pounds of flint was replaced by 225 pounds of feldspar, 20 pounds of cryolite, 9 pounds of fluorspar, and 14 pounds borax (melted weight).

At the same time, for the sake of economy, the K_2O in KNO_3 of C 1 was replaced by Na_2O, 10 pounds as nitrate and the rest as carbonate. This substitution has been found by experiment[2]

[1] See "Control of Fusibility of Enamels," loc. cit.
[2] "Control of Fusibility of Enamels," loc. cit.

not to alter the fusibility of enamels. The composition resulting from these changes is shown in C 2, Table III. The replacement of the fluorspar is shown in C 3 and C 4, Table III.

Description of the Trials. C 1 was altogether too hard for use on cast iron. The enamel chipped off before the trials were cool.

C 2 had good color and showed no tendency to craze, but its gloss had been impaired, leaving a finish similar to a mat finish on glazes.

C 3 and C 4 had good color and gloss, but were crazed.

TABLE III

	C 1		C 2		C 3		C 4	
	Melted	Raw	Melted	Raw	Melted	Raw	Melted	Raw
Feldspar	225	225	450	450	422	422	410	410
Cryolite	170	170	190	190	190	190	137	137
Fluorspar	100	100	109	109	.....	.....	.....	.....
Borax	114	215	128	241	128	241	128	241
Na_2CO_3	.....	.....	33	57	170	283	235	405
$NaNO_2$	.....	.....	10	27	10	27	10	27
Flint	268	268	.....	.....	.....	.....	.....	.....
KnO_3	43	63	.....	.....	.....	.....	.....	.....
SnO_2	80	80	80	80	80	80	80	80
	1000		1000		1000		1000	

SERIES IV

The object of this series was to attempt to decrease the fusibility of C 4, Series III, so as to stop the crazing. It is well known in enameling practice that crazing can often be cured by making an enamel less fusible. The decrease in fusibility was brought about by substituting feldspar, pound for pound, in place of cryolite in D 1, feldspar for Na_2O in D 2 and D 3, and feldspar for both Na_2O and cryolite in D 4 and D 5. The series is shown in Table IV.

Description of the Trials. The crazing decreased somewhat as the compositions became more refractory but even in D 5, which was too infusible to be workable as an enamel, was still in evidence.

TABLE IV

	C 4		D 1		D 2		D 3		D 4		D 5	
	Melted	Raw	Melted	Raw	Melted	Raw	Melted	Raw	Melted	Raw	Melted	Raw
Feldspar.....	410	410	455	455	480	480	525	525	545	545	590	590
Cryolite.....	137	137	92	92	137	137	137	137	92	92	92	92
Borax.....	128	241	128	241	128	241	128	241	128	241	128	241
Na_2CO_3.....	235	405	235	405	165	285	120	207	145	250	100	172
$NaNO_3$.....	10	27	10	27	10	27	10	27	10	27	10	27
SnO_2.....	80	80	80	80	80	80	80	80	80	80	80	80
	1000		1000		1000		1000		1000		1000	

It is plain that this is one of the cases in which it is impossible to stop crazing by making the enamel more refractory.

SERIES V

Since, as stated above, it seemed useless to make further attempts to stop the crazing in C 4 by altering its fusibility, we decided to return to this formula, cut down the fluorides to an amount known to be safe in enamels for cast iron, raise the Na_2O to a maximum, and then to determine the effect of substituting other ingredients in place of part or all of the soda. The series is shown in Table V.

Description of Trials.

E 1 Crazed badly, mat finish.

E 2 Good enamel, smooth finish, good gloss, no crazing.

E 3 Did not fuse down, a sintered mass.

E 4 Fairly smooth, but had a dull mat finish.

E 5 Beautiful gloss, crazed slightly, had a cream tint.

E 6 Semi-mat finish, crazed badly.

E 7 Beautiful enamel, fine gloss, no crazing, very white and opaque.

CONCLUSIONS FOR PART II

In this part of the investigation, two good, glossy, leadless enamels free from crazing have been produced. These are designated as E 2 and E 7.

TABLE V—MELTED WEIGHTS

	C 4	E 1	E 2	E 3	E 4	E 5	E 6	E 7
Feldspar	410	410	→	→	→	→	→	→
Cryolite	137	120	→	→	→	→	→	→
Borax	128	128	→	→	→	→	→	→
$NaNO_3$	10	10	→	→	→	→	→	→
SnO_2	80	80	→	→	→	→	→	→
Na_2CO_3	235	250					125	
$B_2O_3 3H_2O$			250				125	125
$CaCO_3$				250				
ZnO					250			125
Pb_3O_4						250		
	1000	1000	1000	1000	1000	1000	1000	1000

RAW WEIGHTS

	C 4	E 1	E 2	E 3	E 4	E 5	E 6	E 7
Feldspar	410	410	→	→	→	→	→	→
Cryolite	137	120	→	→	→	→	→	→
Borax	241	241	→	→	→	→	→	→
$NaNO_3$	27	27	→	→	→	→	→	→
SnO_2	80	80	→	→	→	→	→	→
Na_2CO_3	405	430					215	
$B_2O_3 3H_2O$			443				222	222
$CaCO_3$				446				
ZnO					250			125
Pb_3O_4						255		

GENERAL CONCLUSIONS

1. Four leadless enamels of good working properties have been produced. These are designated as A 3, B 1, E 2 and E 7.

2. In enamels of this type, crazing and loss of gloss are liable to occur when the fluorides exceed 15 percent of the melted weight of the glass. See Series II.

3. Enamels of the type usually used for sheet steel are too refractory and too high in fluorides to be used successfully on cast iron. See Series III.

4. It has again been demonstrated that it is not possible in all cases to stop crazing by decreasing the fusibility of an enamel.[3] See Series IV.

5. All the fluxing oxides in common use with the exception of PbO and B_2O_3 give a mat finish in enamels when used in excessive amounts. See Series V.

DISCUSSION

Mr. Flint: I would like to ask if there was any crystallization noticed in those enamels?

Prof. Staley: We obtained a lot of enamels of low finish, distinctly mats in texture, that, considering the way in which they were obtained, we thought were crystalline; but the amount of opacifier in an enamel is so high that it is very difficult indeed to determine the presence of crystals, especially if they should happen to be small. We were therefore not able to identify positively the presence of crystals; but we found, for instance, that whenever we increased the amount of any one oxide, except boric oxide or lead-oxide, to a rather high percentage—much above 15 percent—we got a dull finish. This would correspond to the super-saturation of the enamel with some substance that showed a tendency to crystallize out. I might say that some of the enamels were nice, bright, smooth enamels when hot, but on cooling they become mat, which would indicate that some crystallization had taken place.

[3] Homer F. Staley, "The Cause and Control of Crazing in Enamels on Cast Iron," Trans. A.C.S. Vol. XIV, p. 519.

NOTES ON MAT GLAZES

AMOS P. POTTS, AMES, IOWA

This study is designed to determine the limitations of the theory of matness proposed by R. C. Purdy at the Fourteenth Meeting of the American Ceramic Society.[1]

The glazes are all calculated upon a normative basis. The normative minerals are varied within the following limits:

Glass portion	Pbo, $\frac{1}{2}$ SiO_2	= 0.1 to 0.6 equivalents
	CaO, SiO_2	= 0.55 to 0.05 equivalents
Feldspathic portion	CaO, Al_2O_3, 2 SiO_2	= 0 to 0.3 equivalents
	K_2O, Al_2O_3, 4 SiO_2	= 0.05 to 0.35 equivalents
	K_2O, Al_2O_3, 6 SiO_2	= 0.05 to 0.35 equivalents

PbO, $\frac{1}{2}$ SiO_2 is varied against CaO, SiO_2 from group to group. CaO, Al_2O_3, 2 SiO_2 is varied against combined potassium alumina silicates from series to series. K_2O, Al_2O_3, 6 SiO_2 is varied against K_2O, Al_2O_3, 4 SiO_2 from member to member. The ratio of glass to feldspathic portion is kept constant throughout.

Division into groups is based upon the lead content. The group number corresponds to the number of tenths equivalent of PbO in the glaze. Division into series is based upon the K_2O content. Thus from series 1 to series 4, calcium alumina silicate is increasing at the expense of potassium alumina silicate. The RO combinations studied are shown in groups and series in Table 1.

Each series is divided into members, as K_2O, Al_2O_3, 6 SiO_2 replaces K_2O, Al_2O_3, 4 SiO_2 in steps of 0.05 equivalents. As the total content of potassium alumina silicates decreases from series to series, the number of members of each successive series decreases. Thus series 1 contains 8 glazes; series 2 contains 6 glazes; series 3 contains 4 glazes; series 4 contains 2 glazes. The silica additions from member to member within any series amount to 0.1 equivalent. The total alumina silicates are kept constant at 0.35 equivalents throughout the study; therefore all of the glazes contain 0.35 equivalents Al_2O_3. The SiO_2 contents of the several glazes are shown in Table 2.

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[1] Trans. A. C. S., Vol. XIV, p. 671.

TABLE I—RO COMBINATIONS STUDIED

OXIDE	GROUPS						SERIES
	1	2	3	4	5	6	
PbO	0.1	0.2	0.3	0.4	0.5	0.6	
CaO	0.55	0.45	0.35	0.25	0.15	0.05	1
K_2O	0.35	0.35	0.35	0.35	0.35	0.35	
PbO	0.1	0.2	0.3	0.4	0.5	0.6	
CaO	0.65	0.55	0.45	0.35	0.25	0.15	2
K_2O	0.25	0.25	0.25	0.25	0.25	0.25	
PbO	0.1	0.2	0.3	0.4	0.5	0.6	
CaO	0.75	0.65	0.55	0.45	0.35	0.25	3
K_2O	0.15	0.15	0.15	0.15	0.15	0.15	
PbO	0.1	0.2	0.3	0.4	0.5	0.6	
CaO	0.85	0.75	0.65	0.55	0.45	0.35	4
K_2O	0.05	0.05	0.05	0.05	0.05	0.05	

TABLE II—SILICA CONTENTS OF THE GLAZES

Member		1	2	3	4	5	6
Series 1	1		.....	.....	.....	.....	.....
	2	2.1	.....	.....	.....	.....	.....
	3	2.2	2.15	2.1	.....	.....	.....
	4	2.3	2.25	2.2	2.15	2.1	.....
	5	2.4	2.35	2.3	2.25	2.2	2.75
	6	2.5	2.45	2.4	2.35	2.3	2.25
	7	2.6	2.55	2.5	2.45	2.4	2.35
	8	2.7	2.65	2.6	2.55	2.5	2.45
Series 2	1	1.8	1.75	1.7	.....	.....	.....
	2	1.9	1.85	1.8	1.75	1.7	.....
	3	2.0	1.95	1.9	1.85	1.8	1.75
	4	2.1	2.05	2.0	1.95	1.9	1.85
	5	2.2	2.15	2.1	2.05	2.0	1.95
	6	2.3	2.25	2.2	2.15	2.1	2.05
Series 3	1	1.6	1.55	1.5	1.45	1.4	1.35
	2	1.7	1.65	1.6	1.55	1.5	1.45
	3	1.8	1.75	1.7	1.65	1.6	1.55
	4	1.9	1.85	1.8	1.75	1.7	1.65
Series 4	1	1.4	1.35	1.3	1.25	1.2	1.15
	2	1.5	1.45	1.4	1.35	1.3	1.25

PREPARATION OF TRIALS

Batch Weights. The batch weights will be found in Table 3. In computing these, it was discovered that, in order to obtain the K_2O from feldspar, too much SiO_2 was brought into the glaze to make possible the compounding of the lower members of series 1 in all groups and also those of series 2 in groups 4, 5 and 6.

Preparation of Glazes. The glazes were weighed in gram batch lots, and the weights repeatedly checked. They were then ground in one-gallon ball mills with an equal weight of water for 30 minutes, and stored in glass jars until required for by dipping. The glazes were applied by dipping on biscuit tile, $\frac{3}{4}$ in. $\frac{3}{4}$ in. $\frac{1}{4}$ in. in size manufactured by the American Encaustic Tile Company of Zanesville, Ohio. Each tile was marked with a cobalt pencil with the number of the glaze applied.

Burning. The first burn was made at cone 4, and it was feared that at this heat some of the glazes would flow and cause the tile to stick to the setter. To avoid this, the setter was covered with a layer of kaolin, and the tile were set on this. The setter was then covered by a second setter, which had been washed with waste lead glaze, and the two were carefully luted together. Each setter contained, beside the tile, a small plaque of three shortened cones. Thus for cone 4 burn, the plaque carried cones 3, 4 and 5. The tile were so distributed among the setters that no setter contained two tile of the same glaze. The setters were then placed, along with some other ware, in the No. 3 kiln of the Ohio State Ceramic Engineering Laboratory and burnt until cone 4 was down in about twenty hours. Upon drawing it was discovered that there had not only been no flowing of the glazes, but that the kaolin had so bleached the cobalt markings as to render identification of the glazes very difficult. Therefore in the succeeding burns the kaolin was omitted. The burns made were

	Hours
Cone 4	20
Cone 2	18
Cone 03	16
Cone 07	14

Glazes of groups 1, 2 and 3 were not burned at the two latter heat treatments.

In but one instance (cone 07) was there a difference of half a cone in the different saggers, and in this instance the tile of one setter were thrown out. Two tile of each glaze were burned at each treatment, and it is remarkable how closely they resemble each other even to the shape of glaze in crawling.

DESCRIPTION OF TRIALS

As there are 101 different glazes burned at four different heats, and two tile of each at each heat, making 808 tile in all, no attempt will be made to describe the individual trials. On the other hand, a group description is offered in the accompanying diagrams.

Explanation of Method of Diagramming. It will be borne in mind that as the series was designed, we have a variation of two silicates in the glass portion, viz., PbO, $\frac{1}{2}$ SiO_2 and CaO, SiO_2 and three alumina silicates in the feldspar portion, namely, K_2O, Al_2O_3, 6 SiO_2; K_2O, Al_2O_3, 4 SiO_2, and CaO, Al_2O_3, 2 SiO_2. Therefore the effect of the glass composition can be studied from a bi-axial plotting and the effect of the feldspar variation from a tri-axial plotting. For reasons which will become evident, the variations of the alumina silicate portion will be discussed first.

Figures 1, 2, 3, 4, 5, 6 show the effect of varying proportions of the alumina silicates with the glass composition constant. In studying texture such defects as beading, crawling and parting have been ignored.

Figure I. Glass $\left\{ \begin{matrix} 0.55\ CaO \\ 0.10\ PbO \end{matrix} \right.$ 0.6 SiO_2

Cone 2. As the diagram indicates, none of these mixtures are more than vitrified coatings at this heat treatment, and in all of the mixtures in which CaO, Al_2O_3, 2 SiO_2 has been substituted for potash feldspar we have dry, unvitrified surfaces. The slight increase of SiO_2 from member 2, series 1, to member 8, series 1, has resulted in a very slight increase in the degree of vitrification.

Cone 4. The diagram shows that at this heat treatment a considerable area of mat glazes has been developed, which includes all of series 2, most of series 2 and one glaze in the middle of series 1. This area is surrounded by an area of vitrified coatings and series 4 remains dry, as at the lower cone. This is taken to indi-

TABLE III—BATCH WEIGHT OF GLAZES

Group I

MEMBER	SERIES 1					SERIES 2					SERIES 3					SERIES 4				
	White Lead	Whiting	Feldspar	Clay	Flint	White Lead	Whiting	Feldspar	Clay	Flint	White Lead	Whiting	Feldspar	Clay	Flint	White Lead	Whiting	Feldspar	Clay	Flint
1	.....	.....	.....	.....	.....	25.8	65.0	139.0	25.8	6.0	25.8	75.0	83.4	51.6	18.0	25.8	85.0	27.8	77.4	30.0
2	25.8	55.0	194.6	.....	.....	25.8	65.0	139.0	25.8	12.0	25.8	75.0	83.4	51.6	24.0	25.8	85.0	27.8	77.4	36.0
3	25.8	55.0	194.6	.....	6.0	25.8	65.0	139.0	25.8	18.0	25.8	75.0	83.4	51.6	30.0	.....	.....	.....	.....	.....
4	25.8	55.0	194.6	.....	12.0	25.8	65.0	139.0	25.8	24.0	25.8	75.0	83.4	51.6	36.0	.....	.....	.....	.....	.....
5	25.8	55.0	194.6	.....	18.0	25.8	65.0	139.0	25.8	30.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	25.8	55.0	194.6	.....	24.0	25.8	65.0	139.0	25.8	36.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7	25.8	55.0	194.6	.....	30.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	25.8	55.0	194.6	.....	36.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Group II

1	.....	.....	.....	.....	.....	51.6	55.0	139.0	25.8	3.0	51.6	65.0	83.4	51.6	15.0	51.8	75.0	27.8	77.4	27.0
2	.....	.....	.....	.....	.....	51.6	55.0	139.0	25.8	9.0	51.6	65.0	83.4	51.6	21.0	51.8	75.0	27.8	77.4	33.0
3	51.6	45.0	194.6	.....	3.0	51.6	55.0	139.0	25.8	15.0	51.6	65.0	83.4	51.6	27.0	.....	.....	.....	.....	.....
4	51.6	45.0	194.6	.....	9.0	51.6	55.0	139.0	25.8	21.0	51.6	65.0	83.4	51.6	33.0	.....	.....	.....	.....	.....
5	51.6	45.0	194.6	.....	15.0	51.6	55.0	139.0	25.8	27.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	51.6	45.0	194.6	.....	21.0	51.6	55.0	139.0	25.8	33.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7	51.6	45.0	194.6	.....	27.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	51.6	45.0	194.6	.....	33.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Group III

1	.....	.....	.....	.....	.....	77.4	45.0	139.0	25.8	.....	77.4	55.0	83.4	51.6	12.0	77.4	65.0	27.8	77.4	24.0
2	.....	.....	.....	.....	.....	77.4	45.0	139.0	25.8	6.0	77.4	55.0	83.4	51.6	18.0	77.4	65.0	27.8	77.4	30.0
3	77.4	35.0	194.6	.....	.....	77.4	45.0	139.0	25.8	12.0	77.4	55.0	83.4	51.6	24.0	.....	.....	.....	.....	.....
4	77.4	35.0	194.6	.....	6.0	77.4	45.0	139.0	25.8	18.0	77.4	55.0	83.4	51.6	30.0	.....	.....	.....	.....	.....
5	77.4	35.0	194.6	.....	12.0	77.4	45.0	139.0	25.8	24.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	77.4	35.0	194.6	.....	18.0	77.4	45.0	139.0	25.8	30.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7	77.4	35.0	194.6	.....	24.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	77.4	35.0	194.6	.....	30.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE III—BATCH WEIGHT OF GLAZES—Continued

Group IV

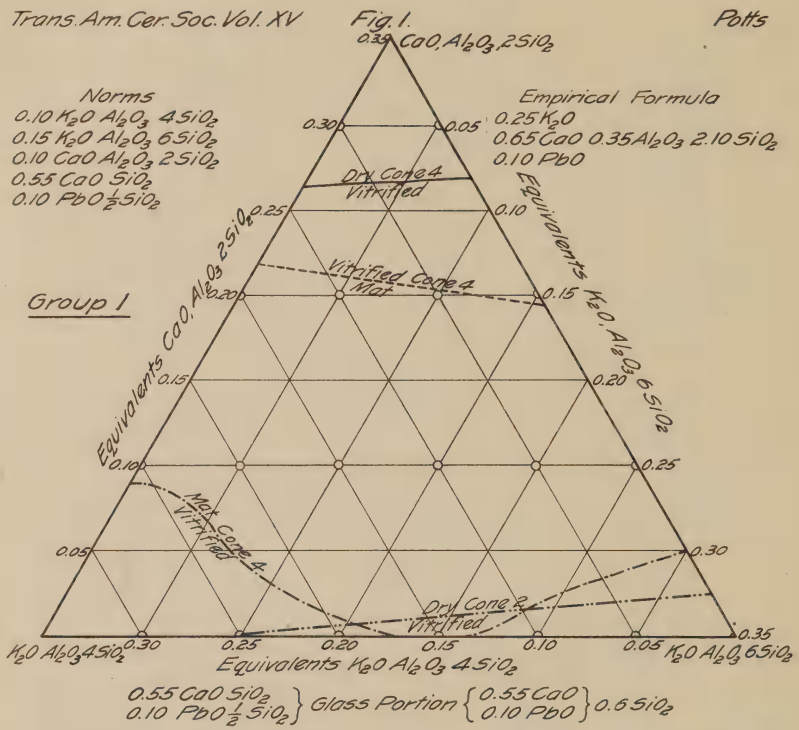
1											103.2	45.0	83.4	51.6	9.0	103.2	55.0	27.8	77.4	21.0
2						103.2	35.0	139.0	25.8	3.0	103.2	45.0	83.4	51.6	15.0	103.2	55.0	27.8	77.4	27.0
3						103.2	35.0	139.0	25.8	9.0	103.2	45.0	83.4	51.6	21.0					
4	103.2	25.0	194.6		3.0	103.2	35.0	139.0	25.8	15.0	103.2	45.0	83.4	51.6	27.0					
5	103.2	25.0	194.6		9.0	103.2	35.0	139.0	25.8	21.0										
6	103.2	25.0	194.6		15.0	103.2	35.0	139.0	25.8	27.0										
7	103.2	25.0	194.6		21.0															
8	103.2	25.0	194.6		27.0															

Group V

1											129.0	35.0	83.4	51.6	6.0	129.0	45.0	27.8	77.4	18.0
2						129.0	25.0	139.0	25.8		129.0	35.0	83.4	51.6	12.0	129.0	45.0	27.8	77.4	24.0
3						129.0	25.0	139.0	25.8	6.0	129.0	35.0	83.4	51.6	18.0					
4	129.0	15.0	194.6			129.0	25.0	139.0	25.8	12.0	129.0	35.0	84.4	51.6	24.0					
5	129.0	15.0	194.6		6.0	129.0	25.0	139.0	25.8	18.0										
6	129.0	15.0	194.6		12.0	129.0	25.0	139.0	25.8	24.0										
7	129.0	15.0	194.6		18.0															
8	129.0	15.0	194.6		24.0															

Group VI

1											154.8	25.0	83.4	51.6	3.0	154.8	35.0	27.8	77.4	15.0
2											154.0	25.0	83.4	51.6	9.0	154.8	35.0	27.8	77.4	21.0
3						154.8	15.0	139.0	25.8	3.0	154.8	25.0	83.4	51.6	15.0					
4						154.8	15.0	139.0	25.8	9.0	154.8	25.0	83.4	51.6	21.0					
5	154.8	5.0	194.6		3.0	154.8	15.0	139.0	25.8	15.0										
6	154.8	5.0	194.6		9.0	154.8	15.0	139.0	25.8	21.0										
7	154.8	5.0	194.6		15.0															
8	154.8	5.0	194.6		21.0															

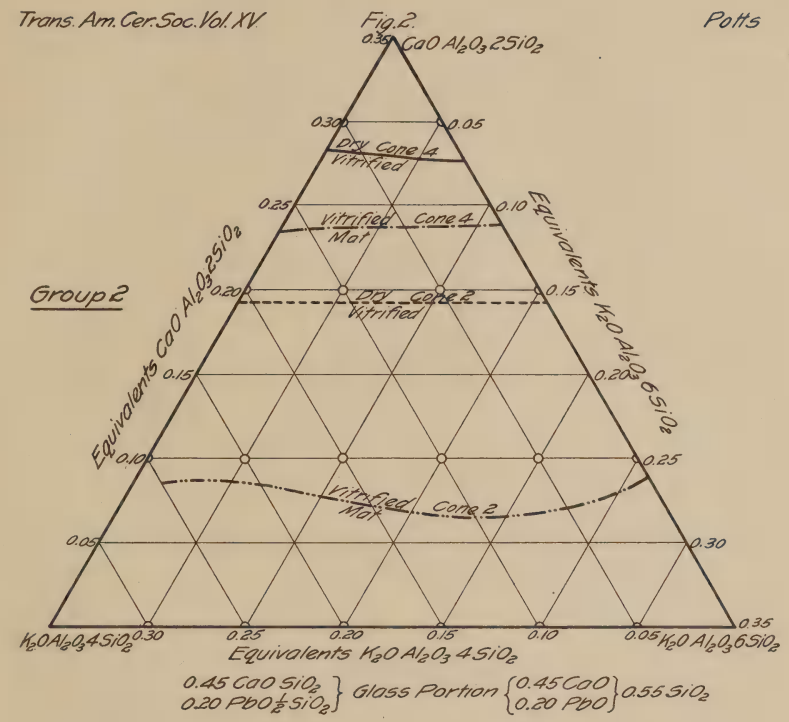


cate that the substitution of CaO, Al_2O_3, 2 SiO_2 for a portion of the K_2O, Al_2O_3, 4 or 6 SiO_2 is conducive to the development of a mat texture.

Figure II. Glass $\left\{ \begin{matrix} 0.45 \text{ CaO} \\ 0.20 \text{ PbO} \end{matrix} \right.$ 0.55 SiO_2

Cone 2. Due to the increased fusibility of the glass portion, all of series 1 (potash alumina silicate) which were vitrified coatings in group 1 have become mat; also the area of vitrified coatings has moved across the diagram toward the CaO, Al_2O_3, 2 SiO_2 apex so as to include all of series 2; and series 3 seems to be about on the border line between dry and vitrified surfaces.

Cone 4. At this heat treatment the effect of the greater fusibility of the glass is not so marked as at the lower heat. The area of matness has broadened but slightly as compared to group 1 and

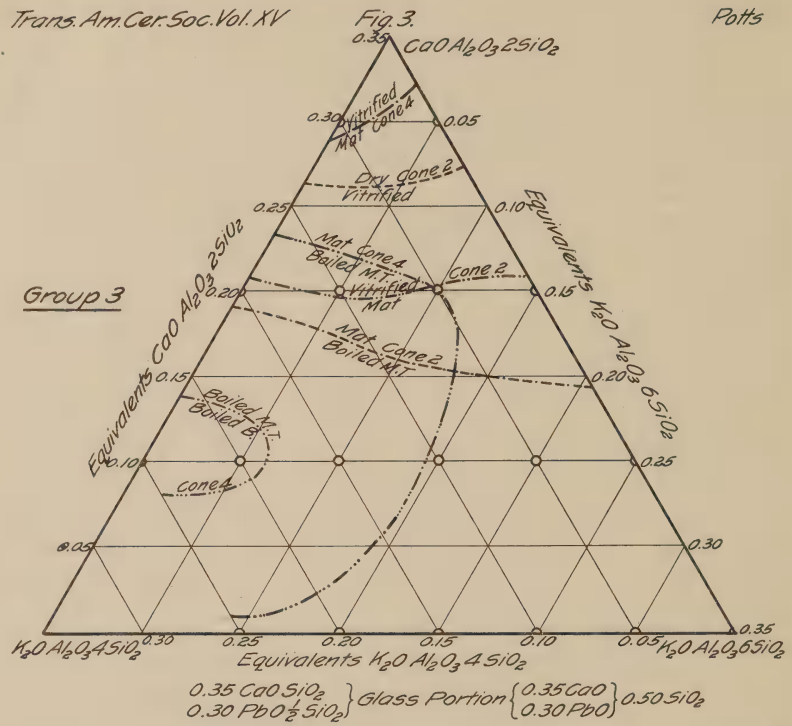


now includes all of series 1, 2 and 3 with 4 still dry and unvitrified. It will be observed that on this diagram, as in the majority of cases, the boundaries of the several areas are parallel with the potash alumina silicate axis.

Figure III. Glass $\left\{\begin{matrix} 0.35\ CaO \\ 0.30\ PbO \end{matrix}\right.$ $0.5\ SiO_2$

Cone 2. This figure illustrates still further the effect of the increased fluidity of the glass portion. Series 3 has now become the boundary between vitrified coatings and mat surfaces. Series 4 is still dry; but series 1 and 2, while still of the mat texture, show marked evidence of boiling.

Cone 4. This figure introduces a new complication. Members 1 and 2 of series 2 are clear glasses more or less bubbled; member 3 of this series and members 1, 2 and 3 of series 3 are mat in texture

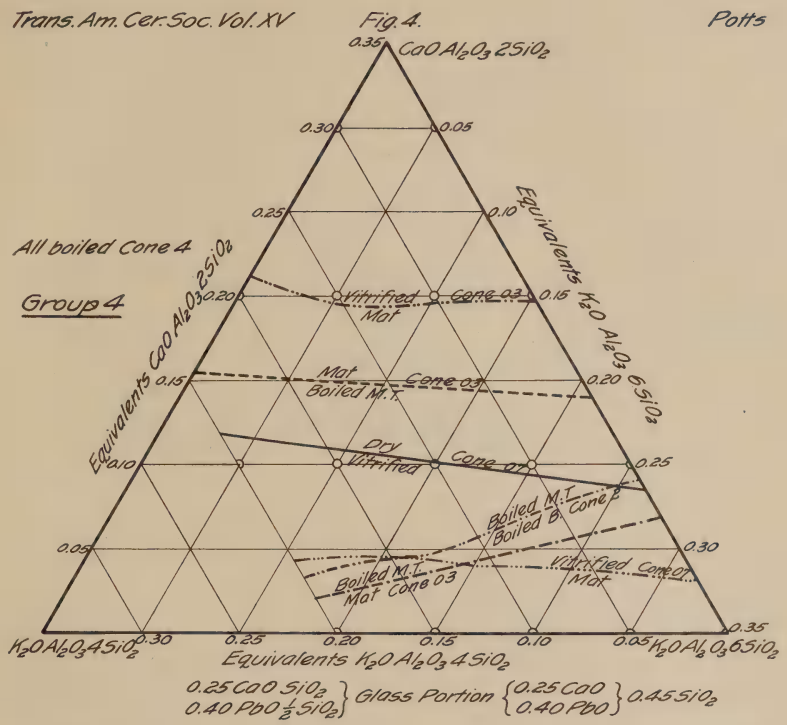


and also boiled, while the rest of the glazes, with the exception of member 1, series 4, are mat. This is the first instance of a variation between K_2O, Al_2O_3, 4 SiO_2 and K_2O, Al_2O_3, 6 SiO_2 producing a marked effect and in this instance the very slight increase in SiO_2 seems to correct the boiling and in one instance to change a clear bubbly glass to a bubbly mat.

Figure IV. Glass $\left\{ \begin{matrix} 0.25 \text{ CaO} \\ 0.40 \text{ PbO} \end{matrix} \right.$ 0.45 SiO_2

Cone 07. Series 1 is all mat.

Series 2 is on the border line between dry and vitrified surfaces. Referring back, it will be seen that in degree of maturity these glazes are at cone 07 about midway between those of groups 1 and 2; at cone 2 the substitution of 0.25 PbO, $\frac{1}{2}$ SiO_2 for 0.25 CaO,



SiO_2 has lowered the heat treatment necessary to produce this degree of fusion about 9 cones.

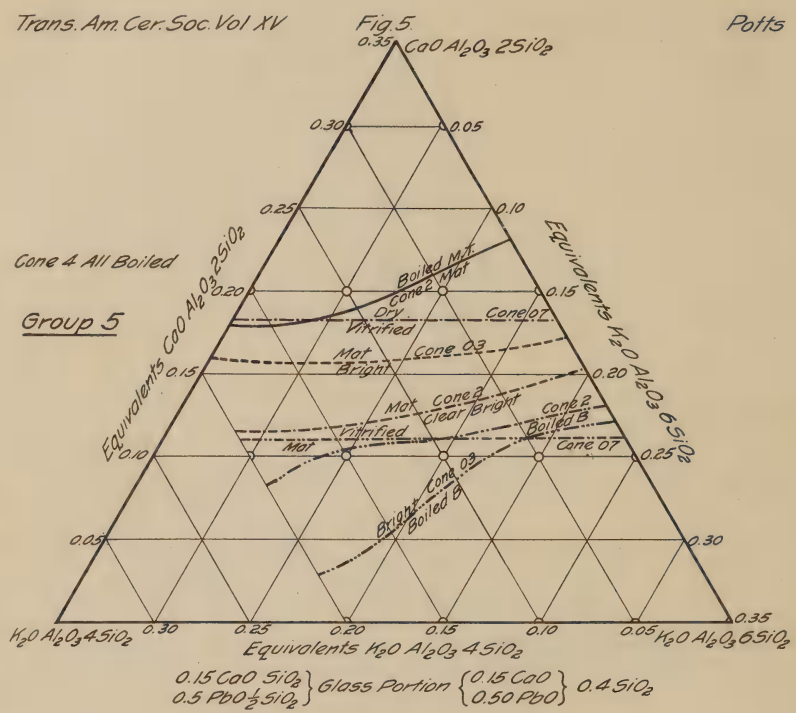
Cone 03. Series 1 are mat. Series 2 are bubbled mats. Series 3 are about the border line between mat glazes and vitrified coatings with a more or less mat surface.

Cone 2. All the glazes are badly bubbled at cone 2. Those of series 1 are clear glasses full of bubbles, while those of the other series are boiled opaque masses with more or less of a mat texture.

Cone 4. All glazes are badly bubbled, the lower members of series 1 and 2 being clearer than the higher members.

Figure V. Glass $\left\{\begin{matrix} 0.15\ CaO \\ 0.50\ PbO \end{matrix}\right.$ $0.4\ SiO_2$

Cone 07. Series 1 are mat. Series 2 is the boundary between vitrified surfaces and mat. Series 3 are dry but apparently close



to boundary between dry and vitrified coatings. Series 4 are dry. Again on referring back, it will be seen that these mixtures approach very closely the degree of fusion at 07 exhibited by those of group 2 at cone 2.

Cone 03. Series 1 are bubbled clear glazes. Series 2, members 2, 3 and 4 clear glazes; 5 and 6 are bubbled clear glazes. Series 3 and 4 are hard mats.

Cone 2. Series 1 are bubbled clear glazes. Series 2, number 1, are good clear glaze; the balance are bubbled. Series 3, numbers 1 and 2 are bubbled mat glazes; 3 and 4 are smooth mats. Series 4 are badly boiled mats.

Cone 4. All glazes are bubbled or boiled. It will be noticed that in the series in which the mixture is mat, a slight increase in silica will correct the bubbling tendency, but in those in which it is clear and bright the increase of silica increases the bubbling tendency. Compare series 2 at cones 03 and 2 with series 3, cone 2.

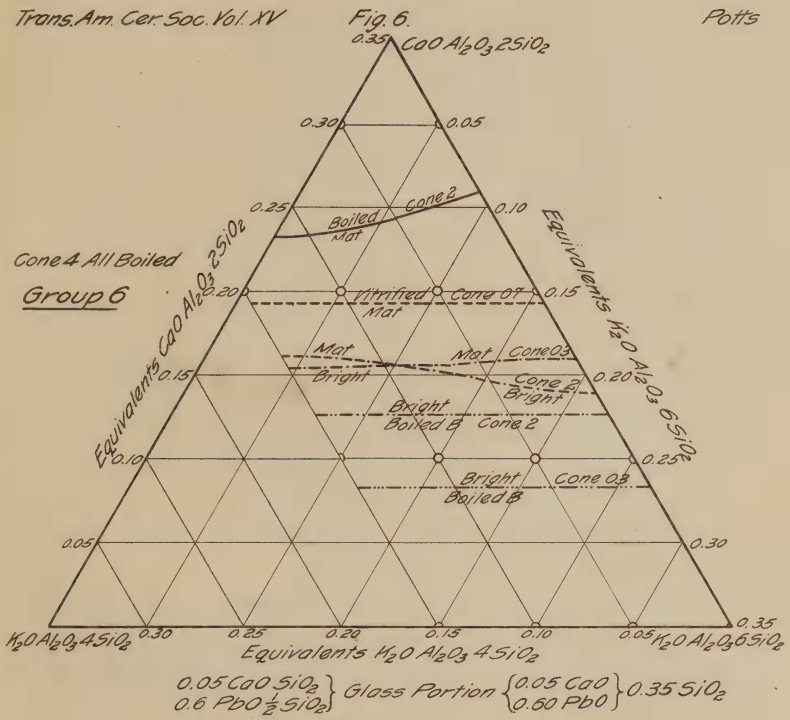


Figure VI. Glass $\left\{\begin{matrix} 0.05\ \text{CaO} \\ 0.60\ \text{PbO} \end{matrix}\right.$ $0.35\ SiO_2$

Cone 07. Series 1 and 2 have mat texture. Series 3 is on the boundary between vitrified surfaces and mat texture. Series 4 is dry.

Cone 03. Series 1 are bubbled clear glazes. Series 2 are bright clear glazes. Series 3 and 4 are mat glazes.

Cone 2. Series 1 and 2 are bubbled clear glazes. Series 3 are mat glazes. Series 4 are bubbled masses, mat in texture.

Cone 4. All are boiled or bubbled.

Summary. A study of the six figures reveals the following:

1. Each of the mixtures in the process of fusion passes through a stage at which it has a mat texture.

2. The fusibility of these mixtures is more dependent upon the composition of glass than of the feldspar portion.

3. In nearly all cases, series 4, containing 0.3 CaO, Al_2O_3, 2 SiO_2, is more refractory than any other series, but among the other three there is very little difference.

4. In but one or two instances did the change from K_2O, Al_2O_3, 4 SiO_2 to K_2O, Al_2O_3, 6 SiO_2 produce any marked effect.

5. The evidence of these six figures confirms the theories presented by Professor Purdy in every detail, except as regards the formation of the K_2O, Al_2O_3, 4 SiO_2, which does not seem to be effective as he would seem to expect.

Variation in Composition of Glass Portion. As has already been shown, the introduction of K_2O, Al_2O_3, 4 SiO_2 as a possible factor in the production of the mat texture seems hardly to have been justified; therefore, the study of the effect of the glass composition is very much simplified, as we can plot the average condition of the glazes of each series on a diagram in which composition is used as ordinate and heat treatment as abscissa and determine graphically the areas within which the various mixtures will produce the mat texture. This is done in the following curves.

Figure VII.

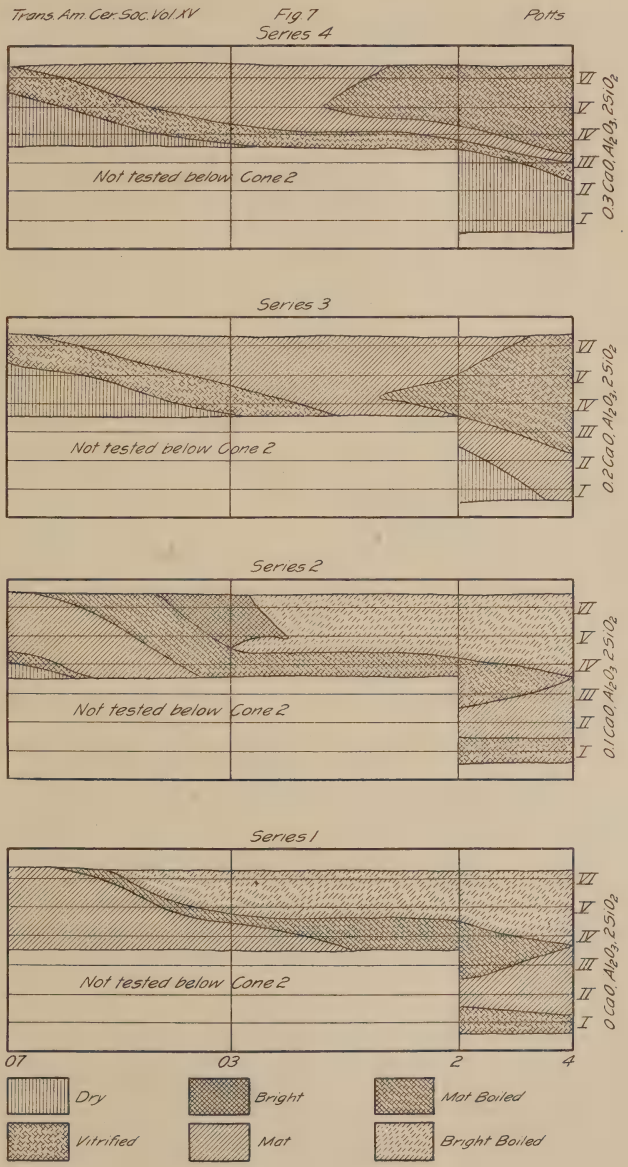
Series 1—Feldspar 0.35 K_2O, Al_2O_3, 4 to 6 SiO_3
Series 2—Feldspar 0.15 K_2O, Al_2O_3, 4 to 6 SiO_2
0.1 CaO, Al_2O_3, 2 SiO_2
Series 3—Feldspar 0.15 K_2O, Al_2O_3, 4 to 6 SiO_2
0.2 CaO, Al_2O_3, 2 SiO_2
Series 4—Feldspar 0.05 K_2O, Al_2O_3, 4 to 6 SiO_2
0.3 CaO, Al_2O_3, 2 SiO_2

These curves are presented as a single figure in order the better to illustrate the points of interest.

1. It will be noted that it was extremely unfortunate that some of the glazes were left out of the cone 03 burns. This point was not noticed in time, but as the tile were grouped on being drawn from the cone 2 burn, we did not seem justified in including these glazes in the crowded lower burn.

2. In every case the heat range at which the mixtures exhibit the mat texture advances regularly with decrease of PbO, $\frac{1}{2}$ SiO_2 and increase of CaO, SiO_2.

3. Those mixtures highest in PbO, $\frac{1}{2}$ SiO_2 in series 1 and 2 passed regularly with increased heat treatment from mat to boiled mat, to


Trans. Am. Cer. Soc. Vol. XV
Fig. 7
Potts
Series 4
Not tested below Cone 2
0.3 CaO Al2O3 2SiO2
Series 3
Not tested below Cone 2
0.2 CaO Al2O3 2SiO2
Series 2
Not tested below Cone 2
0.1 CaO Al2O3 2SiO2
Series 1
Not tested below Cone 2
0 CaO Al2O3 2SiO2
VI
V
IV
III
II
I
07
03
2
4
Dry
Bright
Mat Boiled
Vitrified
Mat
Bright Boiled

clear glassy, to boiled glassy. In series 3, they remained mat over a considerable range and had not, within the limits of this investigation, shown any tendency to become clear or bright. In series 4, the progress of fusion indicates a very abrupt passage from a vitrified coating of mat texture to a violently boiled mass.

4. For low fire, cone 07 to 03, mat glazes (those of series 1) groups 4 and 5 seem to recommend themselves. For the range 03 to 2, the glazes of series 3, groups 4, 5 and 6, are to be preferred. For mat glazes at cone 2 or above the glazes of series 1, group 2, seem most suitable.

CONCLUSIONS

The results of this investigation confirm in general Professor Purdy's theories. The only modifications to his theory would be:

1. To belittle the effect of K_2O, Al_2O_3, 4 SiO_2

2. To emphasize the effect of K_2O, Al_2O_3, 6 SiO_2, as compared to CaO, Al_2O_3, 2 SiO_2 in the low fire, cone 07 to 03, and in the higher fire, cone 2 to 4, mat glazes.

3. To indicate that CaO, Al_2O_3, 2 SiO_2 alone, or as the predominating alumina silicate (0.3 or above out of a total 0.35) is not conducive to the formation of the mat or any other glaze texture.

DISCUSSION

Mr. Purdy: I would like to have a statement from the author of that paper as to whether or not this is a workable theory: My theory, you remember, was presented not so much as a theory of the cause of matness as a working theory for the development of the mat glazes.

Prof. Potts: All I can say is that we have tried out the theory this year, therefore I would answer Professor Purdy's query in the affirmative—it is a working theory for the production of mat glaze.

Prof. Staley: In regard to the norm constitution of glazes, I stand sponsor for this in a way, being the first one to suggest it in our Transactions. I might say that, to my mind, it is simply a method of calculation pure and simple. It is a means of obtaining an end. I do not believe anyone has ever claimed that these minerals do positively form. It is simply a method of calculation which amounts to variation of groups of oxides rather than variation of single oxides, as is the case in the use of the ordinary empirical formulae.

Prof. Potts: In doing this work I had no feeling in the matter; but I believe I understand pretty thoroughly why Professor Purdy offered the theory last year. It was our experience at the laboratory of the University that we could not, by simple manipulation of the empirical formula, formulate a series of glazes with any assurance that we would have glazes of satisfactory mat texture. The limits are too narrow when stated in "molecular" formula: so we adopted this as a means of attack.

In devising the theory, Professor Purdy collected a number of formulae of mat glazes, calculated them on the normative basis, and found that they all conformed very closely to certain limits. For instance, he found no free silica or at most a vary insignificant amount: therefore by working on the normative basis and not putting in any more silica than was necessary to satisfy the norms we believed a series of glazes could be designed which would produce a mat texture. I think you will find that almost every glaze in this study that contained no free silica at sometime or other came through a mat stage. That is more than can be said of a series of glazes as extensive as this but designed on the molecular formula. The only justification of the normative method of calculation is that it is a working hypothesis. If followed it will show you the limits within which a certain type of glaze can be produced, and these limits will be found wider and much more convenient for use than the limits determined by the exactions of molecular formulae.

Dr. Sosman: The use of norms in glaze manipulation is a step in advance such as the petrologists made when they went from oxide analyses to normative analyses; that is, instead of expressing an analysis in terms of lime, alumina, silica, etc., they express it in terms of silicates with which they are familiar. This advances them one step in getting an idea of what is going to come out of their magmas.

Mr. Bleininger: I should like to say in this connection that the very first attempt to calculate glazes was by what you might call a normative system. If you refer to Shumacker you will find he actually used this system in calculating glazes some years before Seger began writing his work. It might be interesting, historically to make this note.

THE CLAY DEPOSITS OF OREGON

BY SAMUEL GEIJSBEEK, PORTLAND, OREGON

INTRODUCTION

In the Pacific Coast States the clay-working industries are in their infancy. The demand for one kind of product is limited, and it becomes a necessity that a clay-working plant be able to produce different classes of burned clay products in order to operate successfully over a certain length of time each year. The common-brick makers with permanent kilns are usually also drain tile manufacturers. Face-brick plants are making hollow ware and drain tile as a side line, while the few sewer pipe factories are also making many kinds of products besides sewer pipe in order to keep going. While clay plants in the East use only one kind of clay to make all their product, conditions demand that clay-working plants along the Pacific Coast use three or four different kinds of clays for their varied class of burned products.

A study of the clay deposits of any locality is, therefore, imperative when satisfactory results are to be obtained. The writer has been confronted ever since he moved to the Pacific Coast with the lack of information regarding the clays of this section. Little information is obtainable, and this has since proven to be of small value.

In gathering information about various deposits and localities for his own use, the writer has done so with a view of having the same made permanent and available for general use. This idea has been partly carried out in presenting to the American Ceramic Society his paper on the "Clay Deposits of Washington" in 1911, and with the present paper on the clays of Oregon he continues this work.

TOPOGRAPHY

The mountain ranges in Western Oregon are separated in the northern part by the valleys of the Willamette River, while in the southern part they run together and form one mountainous region. The most westerly mountain range is called the Coast Range. The next range is the Cascade Range. This range divides the

state into two general sections. In the southwestern part of the state the Coast and Cascade ranges form the Klamath Mountain Range. In the middle part of the state, we have the eastern foothills of the Cascades, which form a large plateau in which are cut several valleys, the rivers of which are tributary to the watershed of the Columbia River. The best known of these are the Deschutes River with its large easterly tributary, the Crooked River, and the John Day River, which traverses central Oregon and finds its source on the western slope of the Blue Mountains. The Blue Mountains form the eastern part of the state with the Snake River as the eastern boundary. In this section are found the valleys of the Owyhee and Malheur Rivers in the south, while the Burnt, Powder, Grande Rounde and Wallowa Rivers form the northern valleys with several smaller streams.

GEOLOGY

The state has been rather neglected in the gathering of data regarding its geological formations. Dr. Condon[1] has published general descriptive material regarding the geology of Oregon, the U. S. Geological Survey has done a little work, but nothing has been done by the state. Recently a Bureau of Mines and Geology has been established, which should be in position to publish some valuable data at some future date. In the southern part of the state, mining has been carried on for a number of years, but no comprehensive reports have been made regarding the geological formations found there.

An outline of the principal formations, as they are known so far, will be given without going into detail. Igneous rocks are found in the Blue Mountains, Cascade Mountains, Klamath Mountains and also in the Coast Range. In the gold belt of the Blue Mountains near Sumpter[2] small areas of gneiss of Archean age are found. The lava flows have been very heavy in the central part of the state, and the extinct craters and the higher peaks of the ranges indicate volcanic activity. No pure feldspar nor quartz deposits have been found so far. Near Roseburg some rhyolite has been

[1] Oregon Geology, by Dr. Thomas Condon, Professor Geology, University of Oregon, 1910.
[2] Gold belt of the Blue Mountains, U. S. Geological Survey by Waldemar Lindgren. 22d Annual Report, 1901.

found which is almost white. Rocks of Cretaceous age are found in several places, especially in the Cascade and Coast ranges. According to Dr. Condon the Rogue River group in western Oregon and most of the Shoshone group in central and eastern Oregon belong to the Cretaceous age. J. S. Diller describes shales convenient to the railroad in the Bear Creek portion of the Rogue River Valley.[3] The Jurassic rocks of the Grants Pass quadrangle consists mainly of dark shales, locally black, but weathering to gray, yellow or brown. None of these shales are worked at present.

In the southern part of the state rocks of Eocene age appear on both sides of the Coast Range. The mountain group known as the Umpqua belongs to this age. The same formation is found near Philamoth and Corvallis, and in many ranges of hills between these two places and the Columbia River. For miles we find the unbroken deposits of this Eocene formation, and it is in this formation that the better grade of clays are found, and from which the better class of clay products are now made.

The Rocky Mountain regions look to the Cretaceous age for their coal. According to Dr. Condon the Pacific Coast has later coal deposits of Eocene age, and much clay is found in connection with the coal. Central and Eastern Oregon have hardly any Eocene formation except east of the Wasatch Mountains. The balance of the state is covered with more recent formations, and most of the clays used so far are of the alluvial type.

OCCURRENCE OF CLAY DEPOSITS

The clay deposits of the state are so far known to a very limited extent, but it is safe to expect, that with continued investigation and development large deposits in different localities will be opened up. The deposits now being worked have furnished nearly all the clay products used in the state, and therefore little has been done towards the location of other deposits. A very small quantity of clay products has been shipped into the state, mostly from the plants located in Washington.

The known clays may be classified into two groups: first, residual clays; second, sedimentary clays.

[3] U. S. Geological Survey, Bulletin 380.

MAP OF
OREGON
LEGEND
NAMES OF CITIES UNDERLINED
CLAY DEPOSITS ARE BEING WORKED
PACIFIC OCEAN
CLATSOP
COLUMBIA
WASHINGTON
TILLAMOOK
MULTNOMAH
HOOD RIVER
WASCO
SHERMAN
GILLIAM
MORROW
UMATILLA
UNION
WALLOWA
YAMHILL
POLK
CLACKAMAS
MARION
LINN
LINCOLN
BENTON
WHEELER
GRANT
BAKER
CROOK
LANE
DOUGLAS
COOS
CURRY
JOSEPHINE
JACKSON
KLAMATH
LAKE
HARNEY
MALHEUR
Astoria
Kalama
St. Helen
Vancouver
Hood River
The Dalles
Moro
Condon
Fossil
Heppner
Weston
Pendleton
La Grande
Enterprise
Baker City
Canyon City
Prineville
Bend
Weise
Vale
Burns
Albany
Corvallis
Eugene
Cottage Grove
Sutherlin
Roseburg
Coquille
Marshfield
Gold Beach
Grants Pass
Tolo
Jacksonville
Ashland
Klamath Falls
Lakeview

Residual Clays. In several places in southern and eastern Oregon residual clays are said to have been found. These clays do not possess much plasticity and are hard to distinguish from the rock formation proper. In eastern Oregon they appear to have been products of rock decomposition, affected subsequently by the intense heat of volcanic action, and are now partly burnt and in some instances fused to a solid mass. Some fine specimens of this character of clay have been found to the south of Baker in eastern Oregon. No kaolin deposits of a commercial value have been located so far.

Sedimentary Clays. Under sedimentary clays can be counted nearly all the clay deposits worked at present in the state. First there are the common surface clays and loams, principally found in the valleys of the river basins. In the Willamette Valley this class of clay is used for the making of common brick and drain tile. At Newberg, efforts have been made to use such clay for face brick purposes, but with little success from a commercial standpoint.

Next there are the deposits of white, buff and red burning plastic clays. Judging from present indications and personal observations and examinations, the main belt of these clays runs north and south along the eastern slope of the Coast Range. These are all sedimentary and are so far principally found in pocket formations and very much intermixed. In this belt clays have been found at Timber, Cherry Valley, North Yamhill, Carton, Willamina, Butler, Buena Vista, Bellfountain, Elmira and Cottage Grove, all within the limits of the Willamette Valley.

The clays have been classified according to their geological formation, but in order to give a better idea of different kinds of clay found and the purpose for which they could be used, the following classification according Dr. H. Ries[4] is cited:

Kaolins,
Fire clays,
Stoneware clays,
Terra cotta clays,
Sewerpipe clays,
Pressed brick clays,

[4] Clays, their Occurence, Properties and Uses by Dr. H. Ries.

Face brick clays,
Paving brick clays,
Fire proofing and hollow ware clays
Common brick clays,
Drain tile clays,
Slip clays.

The different kinds of manufactured products made from the clays according to this classification, with special reference to the state are as follows: Kaolins are used in whiteware potteries and porcelain works, of which there are no establishments in the state. No good deposits of kaolin have been located thus far.

Fire clays may be divided into high and low grade clays. Of the high grade fire clays no deposits have been found so far. Some clays have been worked and used for low-grade fire brick, but this material has not equaled the products imported from other states. No fire clay products are being made in the state.

Stoneware clays have been found in several localities, but all have not proven to be good clays. The better deposits are worked and shipped to Portland, where they are used by the Pacific Stoneware Co. in the manufacture of stoneware products.

While some terra cotta clays of good quality are found, none of them are worked or used in the making of the finished product.

Sewerpipe clays are also found in several places, but are worked only at one place and shipped then to the Western Clay Co., of Portland, the only plant of this kind in the state.

Pressed brick and face brick clays are closely allied, and may be divided into the red, buff and white burning variety. There are three plants making red face brick, and only one of these, the Pacific Face Brick Co. of Willamina, is making buff and white brick,

Some paving brick clays have been found and tested, and have given excellent results. These are, however, located some distance from existing transportation lines, and none of them are worked at present. However, with the increased demand for better roads and brick paved streets in the cities, it will be only a question of time until such clays will be used in the manufacture of paving brick.

Fire proofing and hollow ware clays are found at several places, and are worked by several factories. The demand for such clay

products is steadily increasing, and other yards are contemplating the manufacture of this class of clayware.

Common brick clays are found all over the state, and, of course, are worked more than the others. There are some sixty brick yards, big and little, in the state of which the majority are soft-mud yards. The clays used vary from the best plastic clays to the poorest material, and the results obtained vary accordingly. Some yards are making common brick which, with a little care in handling and burning, could be easily classified as face brick.

Drain-tile clays are used by several plants, and the plastic brick clays are mostly used for that purpose. Drain tiles are in large demand in the western part of the state and several factories make a specialty of that class of clayware.

Slip clays are not in demand in the state and have therefore never been used, although several deposits have been found and tested which would make good slip clays.

GENERAL LOCATION OF PRINCIPAL CLAY DEPOSITS

The government statistics for 1911, which are the latest available at the present writing, show 63 clay-working firms in the state, and therefore the state cannot very well be divided into districts. A short description of the principal clay deposits and their workings will be given, starting with the northern part of western Oregon, then taking the largest clay-working district in the state, which is Portland and vicinity, describing next the deposits lying southwards in western Oregon, and closing with the deposits of central and eastern Oregon.

Western Oregon. Around Astoria, near the mouth of the Columbia River, some good shales have been found. These shales belong to the Coast Range deposits, and have been worked for a year or so, but at present are idle. Towards the south of Astoria, some white clay has been found in pocket formation, and was tested for the manufacturing of whiteware by Astoria parties, but no commercial development of the deposit has been made.

Along the Pacific slope of the Coast Range near Tillamook, some good plastic red and buff burning clays have been found, and will be worked very shortly in the manufacture of brick and drain tile. These clays are round with very little overburden, and are all of a plastic nature. The color in green state varies from black to gray.

In the foothills of the Coast Range on the eastern slope, west of Portland, we find several well-defined deposits of good clays. On the line of the Pacific Railway & Navigation Co., between Buxton and Timber, the railroad cuts through several banks of plastic clays, and shows that these deposits are very regular, and can be worked with little expense. None of these deposits have been worked so far, but much testing has been done, and manufacturing enterprise will be started at some future date. At Forest Grove, Hillsboro and North Plains, we find brick yards making common brick and some drain tile. They are using the surface clays as they are found; very little stripping must be done, and the product is a good sound brick.

In the Portland district, we have three brick yards working practically the same clay. These are the Standard Brick & Tile Co., the Friberg Bros. yard, and the Portland Brick & Tile Co., all located in the western part of the city in the heights section. The first yard is located on the Canyon Road near Sylvan, the second yard on Varnes Road, and third is situated on Linnton Road. The clay used by these plants is from a disintegrated basaltic formation and is plastic. It is obtained from an open bank and prepared for the brick machine by the use of disintegrator and smooth rolls. Friberg Bros. have used a steam shovel for several seasons. The main product of these yards is common brick. The Standard Brick & Tile Co. have used this clay for the making of hollow ware and drain tile, and have done some experimenting with the same for the making of sewer pipe.

Some years ago there were several soft-mud yards in East Portland, but with the rapid growth of the city, most of these yards have been abandoned, the clay pits leveled and laid out in city lots, and only two yards are still in existence. These are the Versteeg-Kern Brick Co. in East Portland, and A. N. Willis in South Portland or Sellwood. The clay used by these yards is alluvial drift clay, and is obtained at the surface of a thickness of about five feet. It is quite sandy in streaks, and has been used only for the manufacture of common brick. In North Portland, near St. Johns, these surface clays have been worked for several years, but the yards have not branched out to any extent.

In the vicinity to the south and east of Portland, there are sev-

eral clay deposits now being worked. At Beaverton a surface clay has been worked by the Beaverton Clay Mfg. Co. for the manufacture of common brick. Drain tile also has been made here by the intermixing of some plastic clay but with little success. The deposit is underlaid with a blue plastic clay, which has not yet been worked.

A deposit of plastic red clay crops out along the Oregon Electric right of way south of Garden station, and has been traced eastward to the Southern Pacific Railroad near Cook. This clay is a better grade of plastic red burning clay, and has been tested yielding good red brick well adapted for face brick purposes. At Tualatin, a deposit of surface clay intermixed with gravel has been worked for the manufacture of common brick and drain tile. A deposit of better grade of clay has been opened and worked for a short time about a mile south of that place.

On the Cazadero Electric line, in the hills which form the watershed between the Sandy and Clackamas Rivers, there are several deposits of good red burning clays. These clays, somewhat stratified, are brown-gray in the upper part of the bank, but further down they are blue gray. They are fairly plastic, work well, and are worked at Hogan by the Columbia Clay Works and at Anderson by the Unique Brick & Tile Co. The plant at Hogan works these clays all the year around in the manufacture of common brick, hollow ware and drain tile; at Anderson only common brick are made. Excellent clays have been found near Eagle Creek and at Estacada, where a deposit was worked some years ago for making drypress brick but without success.

Along the west side of the hills near the mouth of the Clackamas River, at Park Place, along the right of way of the Southern Pacific some buff-burning clays have been found and worked. These clays were used by the Pacific Stoneware Co. of Portland, and by Charles Fischer at Milwaukee. The clay of a semi-plastic nature is found in pocket formation with six to eight feet overburden. It stands considerable heat and has been used for fire brick purposes. The clay cracks much in drying, and its use for stoneware manufacturing has been abandoned.

In Willamette Valley the most extensive development of clay beds has been done some distance west of North Yamhill by the

Western Clay Co. of Portland. The clays are extensively worked and belong to the clay belt mentioned before. The over-laying burden of surface clay is cleared off the main deposits, and the clay is mined in open bank and pit. The clay is shipped to Portland to be used in the manufacture of sewer pipe, hollow ware and face brick. All the clay obtained here is red burning and plastic. A small plant at North Yamhill works the same clay, but from a different deposit.

At Newberg, the Newberg Face Brick Co. operated a plant, which has since been totally destroyed by fire, using surface clay, in the manufacture of face and common brick. The surface clay has not proven a great success for face brick purposes, and the burned brick must be sorted to proper size. A new deposit of a plastic blue clay has recently been opened up, lying some twenty feet below the surface clay, and both clays are now used in a mixture. A surface clay is used at McMinnville by Jacob Seiters and at Donald by two small plants. The Donald Brick & Tile Co. is working the surface clay by the stiff-mud process. The Goode-Venhoomissen Brick Co. is operating a soft-mud yard. Several smaller yards in this part of the Willamette Valley, at Schools, Canby, New Era, Sherwood, Woodburn and other places, use surface clay in making common brick and drain tile.

The white and buff burning clays of the clay belt are worked on a large scale at Willamina by the Pacific Face Brick Co. of Portland. The clays are mined in the same pit and have a face of about forty feet. They mine a black plastic clay which burns white, a dark gray colored clay which burns buff, and a gray-green clay which burns red. There are other clays of different shades, but these are mixtures of the main ones. The clay is hoisted from the pit and stored. The greater part of the year the clays are worked direct and ground in dry pans, but in the wet seasons it becomes rather hard to handle the clay on account of the plasticity and stored clay is mixed with the clay as mined. The clays are found as a distinct pocket formation and are so intermixed that it requires considerable care and attention to obtain the proper kind of clay for the different mixtures. At the north side of the pit a large deposit of reddish-brown clay derived from decomposed basalts is found and is used in the manufacture of clay products.

This deposit overlays the pocket formation of white and buff burning clays, and is over a hundred feet in thickness.

Five miles west of Willamina at Butler are the White and buff-burning clay properties of the Western Clay Co. and of the Pacific Stoneware Co. both of Portland. The clays are well defined, and not much intermixed, and are found on the western slope of the hillside, having very little overburden. The clay of black and gray color had been found to a depth of about twenty feet and has been used by the Western Clay Co. for making fire brick. The Pacific Stoneware Co. has used this clay as their main body for several years. Outcrops of white and buff-burning clays are found still farther west, and some good prospects are located near Grande Rounde. Judging from a close examination of the section and its geological formation, these look promising for further development of clay properties and as soon as better railroad and transportation facilities are offered, more factories will be located there.

Large operations are carried on at Salem by the Salem Tile & Mercantile Co. which is using surface clays, obtained to a depth of eight feet below the surface. The more plastic material is used for drain tile, and common brick is made of the sandy material. The State Penitentiary located here is using similar surface clay, in the manufacture of common brick by the soft-mud process.

Near Albany, the Albany Brick & Tile Co. has opened a large deposit of good surface clay, and has been making common brick. The Corvallis Brick & Tile Co. of Corvallis is working surface clay for the manufacture of brick and drain tile. This company has been making fire brick from a buff-burning clay obtained near Bellfountain. The bricks have been used for fire box lining in brick kilns, and have stood up all right.

At Dallas, Falls City, Airlie, Monmouth and Buena Vista, in Polk County, clays have been found and worked to some extent. Some of these are of the better grade of plastic red and buff-burning clays, but no extensive manufacturing has been carried on so far.

A new clay bank has been opened up by Field Bros. at Monroe, to be used in the manufacture of common brick and drain tile. The clay is plastic in nature and burns to a good color. The same company formerly operated a yard about a mile west of Eugene,

where they opened a large deposit of plastic clay in disintegrated basaltic formation. W. A. Cook has been working a surface clay of a sandy nature several miles north of Eugene, and is making common brick from it.

Along the new railroad from Eugene to Coos Bay, new clay deposits have been located in making the railroad cuts. The clays at Elmira have been tested and will produce good brick and tile. White-burning clays of a plastic nature have also been found there. These clays have been worked only on small scale.

At Cottage Grove, A. E. Gleason has been working a surface plastic clay for the making of common brick. White plastic clays have been found some distance east of Cottage Grove, but no development has been carried on.

South of Cottage Grove, in the mountains and hills of the Umpqua formations, the first deposit worked is at Sutherlin, where brick and drain tile have been made for years. The clay is found without overburden and is located along the hillside, evidently a washed clay from the original rock formation of the hills. The clay burns a good red color, and makes an excellent product. The Sutherlin Brick & Tile Co. is operating the deposits at present.

At Roseburg a clay deposit has been opened for the manufacture of common brick. The clay used is also a surface formation. Around Grants Pass, some good clays are found in the valleys and used for common brick making. At Tolo, clay deposits have been opened and worked for brick and drain tile. The clay is of a plastic shaley nature. At Jacksonville, good clays are worked by the Jacksonville Brick & Tile Co. for brick and drain tile. Surface clays are worked at Klamath Falls for the making of common brick.

Along the Pacific Coast and especially in the Coos Bay district good clays have been found. Some of a shaley nature and are found in connection with the coal formations. None of the deposits have been worked, however, and the brickmaking in this section is confined to surface clays. There is a plant at Marschfield and also one at Bandon for the manufacture of common brick.

This will complete the description of the principal clay deposits of the western part of the state. There is no doubt but that this part of the state is well provided with good clays, and that ulti-

mately the clay industry will develop rapidly. It should, however, be borne in mind that this part contains also the largest amount of standing timber in the state, and that it is also not very densely populated.

CENTRAL AND EASTERN OREGON

The clay deposits of Central Oregon are not developed to any extent. This is due to the condition of the country. There are very few towns of any consequence and the whole country is sparsely settled; therefore clay products are not in great demand. A surface clay is worked at Prineville by McNealy and Bulger for the making of common brick. The Bend Brick Co. of Bend is also making common brick from a deposit of plastic clay. A good shale clay has been found in this locality and has been tested for the making of sewer pipe, but the results were not very satisfactory.

In several places along the Deschutes River, deposits of light brown-gray material are found. This material is very light in weight and does not disintegrate in water. If ground fine, it will show little plasticity, and will stand medium temperature. Judging from an analysis made of such material, it appears to belong to the infusorial earth class. It has been mistaken for high-class fire clay a number of times, but it will melt to a glassy mass at temperature of about cone 14.

In Eastern Oregon, the clay deposits are a little more developed than in Central Oregon, but not to such an extent as in Western Oregon. In fact, only common brick are made in Eastern Oregon, and there is a market large enough in that section for a face brick and also for a sewer pipe plant. At Weston, a brickyard is operated by Harbour & Towery for the making of common brick. They are using a surface clay, consisting of decomposed volcanic ash, and are making good red-burning brick. These same parties are now operating the clay deposit at La Grande for the manufacturing of common brick. The clay found there is a surface plastic clay and is worked without difficulty.

A deposit of surface clay is used for making common brick at Baker. An attempt was made a few years ago to manufacture a better class of products from clay deposits some five miles south of Baker. Fire brick was the main attempt, but results have

proven that the deposits are not of commercial value. Some plastic white-burning clay has been found along the Oregon Short Line in the same locality, but on account of it being intermixed with other clays no attempts have been made to use these deposits for manufacturing.

The geological formation of the Blue Mountains, which form the main mountains range in the eastern part of the state, is such that there will be found at some future date good plastic white-burning clays and high-grade clay products will eventually be made in that part of the state.

STATISTICS

From the description of the principal clay deposits which are now being worked, it can be easily judged that the value of the manufactured clay products is comparatively small. The statistics of the United States Geological Survey show that in 1895 there were 68 clay plants, while in 1911 there were only 63. It cannot be said that the clay industry in Oregon has grown much in sixteen years, taking the total number of plants into consideration.

The table given herewith will show a comparison of statistics.

Year.	Number firms reporting.	Total value of clay products.	Number in rank of all states.
1895	68	$138,543	37
1901	63	263,891	37
1906	63	506,192	35
1911	63	1,080,025	27

Of the 63 firms reporting in 1911, there were less than three face-brick plants. No vitrified nor fancy ornamental brick plants were in existence. Less than three sewer pipe and pottery plants are located in the state. Common brick were made to the value of $553,652 representing 66,267,000 brick, which were sold at an average price of $8.05 per thousand. The average price of face brick was $26.43. The total value of the clay products manufactured in 1911 was 23.32 percent more than in 1910.

The state ranks number 27 in the list of manufacturing plants of the whole United States according to the total production. The state of Washington, situated to the north, ranks tenth and Cali-

fornia, to the south, is number eight in the same list. Oregon, therefore, is far behind her neighboring states in the value of production of clay products. That not many new plants have been built or their number increased is best proven by the fact that there were more clay plants in the state in 1895 than in 1911. The value of the production, however, increased materially, and most plants therefore have enlarged their operations and are doing a larger business.

NOTE ON THE POPPING OF LIME[1]

S. E. YOUNG, PITTSBURGH, PA.

In a wall plastered with lime mortar, there will occasionally be found small holes which seem to be due to parts of the plaster falling out. In practice this is known as popping or pitting. The cause of popping is not definitely known and has always been a subject of controversy between the contractor and the manufacturer. It is claimed by one that popping is due to an inferior quality of lime and by the other, to poor treatment in slaking and mixing. Neither has been able to prove definitely who should be responsible for this failure and the matter is usually compromised. A test to determine whether lime will or will not pop would eliminate such controversies by preventing the use of improper plaster. The test used at present is to make a small panel of mortar and expose it to conditions similar to those existing in the wall. This test requires considerable time, causing so great a delay as to be generally impracticable, when dealing with a perishable substance like lime.

Recently a thorough investigation of the subject was carried out and different experiments were made on mixes in which the impurities varied, which were burned at different temperatures and which were slaked with different quantities of water. The last variation seemed to be the most promising point of attack, and pats were made from lime slaked with different percentages of water. In a lime paste where too little water was used to slake the lime, small gritty particles were observed. These particles slaked very slowly and could easily be found in the mortar at the end of a week or more. The observation of these particles led to the belief that they might be denser than the sand or other material and would consequently be less transparent.

To investigate this theory a circular can about 6 inches in diameter and 8 inches in height, whose inner surfaces were silvered with mercury, is used. At the bottom of the can is attached a tungsten bulb of 40 watt capacity. In the center of the cover for the can there is a hole about 1 inch in diameter. A mortar containing

[1] By permission of the Director, Bureau of Standards.

some of these particles was examined over the light, and dark, nearly opaque spots were found throughout the mix. The positions of these dark spots were noted and the mortar was exposed to the action of the air. In all cases where the spots were seen, popping occurred. Those at the surface popped first and those which were more deeply imbedded showed signs of expansion and would eventually pop. Several duplicate mixes were made, using a clean white sand with the lime and spreading the mortar about one-sixteenth of an inch thick on a clean glass plate. Samples made from lime slaked with a deficient amount of water showed the spots and all popped; others made from lime slaked with an excess of water did not show any spots and did not pop. The popping occurring in lime burned during its manufacture was not so marked as in well burned lime, and the pats made from this burned lime stood up for a longer time.

To determine whether or not a lime will pop, slake it with a sufficient amount of water to keep the lime from burning and mix with a clean white sand to a good workable mortar. Spread the mortar on a glass plate, keeping the pat about one-sixteenth of an inch thick and examine over the light; if spots are seen, popping will occur.

A PIONEER ATTEMPT TO USE FUEL OIL IN A POTTERY

BY THOMAS GRAY, EAST BOSTON, MASS.

In the first fourteen published volumes of the Transactions of the American Ceramic Society, it is singular how few articles can be found on the subject of kiln firing, and especially on the use of oil as a fuel. In looking over my list of references to fuel and its application, I find only the following:

"Crude Oil," S. G. Burt. Volume I, p. 43.

"Calorific Power of Coal," C. Geisson. Volume I, p. 69.

"Producer Gas," C. Geisson. Volume II, p. 38.

"Electric Furnace." Volume II, p. 192.

"Hard and Soft Coal," Thomas Gray. Volume III, p. 221.

"Relation of Composition to Value in Firing," A. G. Aubrey. Volume IX, p. 713.

"Crude Oil for Firing Kilns," C. H. Griffin. Volume X, p. 175.

"Oil as a Fuel for Burning Ceramic Ware," J. K. Moore. Volume XIV, p. 801.

Then also as abstracts—

By H. E. Ashley from "Calorific Power of Coals," Soc. d'Encouragement pour d'Industrie Nationale. Volume VII, p. 150.

By C. F. Binns, "Fuel and Its Application," from *Pottery Gazette* in May, June, July and August, 1904. Volume VII, p. 274.

Throughout the publications there are some references to fuels and firing, but the above are the only articles having a direct bearing on this subject.

The article of Mr. Moore in Volume XIV brings to my mind that, so far as I have ever been able to learn, the New England Pottery Co. under the management of Gray and Clark, was the first white ware pottery to experiment with oil as a fuel. I think I can safely make the claim that we were pioneers in that line.

It was in the summer of 1892 that an agent of the Standard Oil Co. induced my late partner, Lyman W. Clark, to make the experiment. A 1000-gallon iron tank was sent from their works, and for safety buried on our wharf. The experiment was made under the supervision of Messrs. Gilbert and Barker of Springfield and Boston, Mass. They furnished a pump for forcing oil and steam

into the kiln fire boxes under a pressure of 12 pounds. A brick was placed before the flame as a distributor, but the tremendous blast of flame burned a hole in a very short time, and we were obliged to renew our spreaders.

The kiln used was a regular up-draft, hard coal, hub fed variety, and we made no change for our oil trial. The mouths were bricked up a little more closely than they would have been in using coal, leaving a space 2 in. by 2 in., for the burner about 6 inches from the bottom. So far as I remember, the deposition of carbon gave us no trouble after the kiln was well heated. As it was over 20 years ago, I have forgotten some of the facts.

Our first trial was with two fire boxes only on each side of the door of our 15½-foot kiln. We found the oil would heat; and after two or three trials, we fired the whole kiln with it. The deposition of carbon at the burners kept the fireman steadily on the watch for the first twelve hours. After that they burned better.

The kiln was finished in about the same time as with coal and we used about 2000 gallons of oil, making the cost, at 3½ cents per gallon for oil, higher than if we had fired with coal. The effect on the ware was discouraging for it was covered with a greasy looking scum that could not be removed by washing. The results were no money saved and a kiln to repair before we could use it again. Oil at 12 pounds pressure was too great a trial for the kiln fire boxes. For a first attempt I considered it gave some encouragement. At 4 pounds pressure the results might have been better. Our philanthropy ceased at this point. We left the process for others to adopt, if they so desired.

Mr. Burgess of the International Pottery of Trenton, N. J. made some experiments a few years ago which did not result in his adopting oil as a fuel.

Mr. Burt in Volume I has an article on oil; but having lost my first three volumes, I do not remember what his experience was. Mr. Griffin of the Norton Emery Wheel Co. of Worcester, Mass., in Volume X, p. 175, furnishes his experience under the supervision of Messrs. Gilbert & Barker of Springfield, Mass., and I hope they profited by the experience they got from our trial. I notice they did not attempt forcing steam into the kiln and did try to mix in air. Mr. Moore, in Volume XIV, p. 801, uses a combination of

oil and air. He says "oil as a fuel is in successful operation in some plants." Potters, however, still cling to coal, but prefer gas if they can get it. I saw at the New England Glass Co. at East Cambridge just before they moved to the West, a little oil burner that filled their whole melting pot with flame. It was surprising to see how much flame and heat the little thing could produce.

DISCUSSIONS WRITTEN AFTER READING THE PAPER

Mr. W. D. Gates: Mr. Gray's efforts to get something definite as to the history of the use of fuel oil in burning clay wares interests me, and brings out the matter of getting data on these matters while they can be obtained. Hence I offer my personal recollections in the matter.

In 1880 a man, named I think Zeck, came to me with a fuel oil burner for boilers, and, I believe, had it installed somewhere in Chicago. I remember that one of his experiments was to take a gas pipe, heat it in a forge and bend it into a loop, so there would be a short circular loop in the middle of the length of pipe which could be heated red hot in the forge, leaving both ends distant from the point of heating. He then forced crude oil into one end, and this oil in passing through the red hot loop was transformed into gas, and on touching a match to the other end of the pipe, where the gas was escaping, it burned freely. He then, I believe patented his invention and equipped a fire box lined with pipe inside the fire box. It burned for a while but carbonized, and his pipe filled solid.

At the first convention of the National Brick Manufacturers, when the association organized at Cincinnati in 1886, a representative of the plant at Pullman, Ill., stated that they were dredging clay from Lake Calumet and were mixing crude oil directly with their clay in the soak pits. This is the only instance of this use of oil I have ever known, and I do not think it proved efficient or was long continued.

The use of oil was, however, begun very shortly by the Puringtons in burning brick and was made very effective. The oil was sprayed in with steam and later on in some instances with air, high pressure being used in some cases and in some low.

We started using oil at Terra Cotta about this time, one reason being transportation. At that time, our tracks were not in, and we had to haul coal about a mile. We put in oil and a pipe line, and pumped the oil over. We thus solved our transportation problem and had a better fuel. We used steam at first and air later on. We changed back and forth from coal to oil and from oil to coal several times, our last change, and probably final one being this present spring, and owing to the increased cost of oil. It was a fine fuel, but I think it has now passed into history owing to cost. The only matter of difficulty was its application, regarding which men differed widely. An extreme case of this was that of a small manufacturer who had never seen brick burned except in the common arch kilns and with wood. His plant was in the oil center and he had heard so much about oil as a fuel; that he determined to try it. He loaded a wagon with empty barrels, drove to a storage tank, dipped the oil out of the tank to fill the barrels, drove to his plant, started wood fires in his arches and then threw in oil by the bucketful, and reported a failure. He had no conception of using a fuel otherwise than by throwing it in as he did wood.

The use of oil here in Chicago has been very extensive, the only drawback being price. The increasing demand for the various products of oil, even to road making, is forcing manufacturers to discontinue its use and making them look in other directions and use coal, in the use of which they are looking for better appliances and better applications even as they did with oil in the past.

I consider oil as a fuel now a matter of history only, excepting to some few plants peculiarly located.

Mr. Burt: Mr. Gray is correct in his statement that very little has been written on the use of fuel oil for pottery burning. Hence a few points from the writer's twenty years' experience, with this fuel may be of interest.

The Rookwood Pottery Company installed its oil system and began burning with this fuel in February, 1892, thus antedating the use mentioned by Mr. Gray by over three years. Since that time, oil has been used up to the present time continuously. The writer joined the Rookwood Pottery Company in August, 1892, so has been able to study the problem involved almost from the start.

At first crude oil was furnished us, but this was only for a short time until sufficient refinery capacity was available to refine all the crude. The fuel oil since supplied is the product remaining after the lighter oils, particularly gasoline and kerosene, have been distilled out. This fuel oil varies in specific gravity with the source of the crude and then again at times some kerosene may be left. Our experience covers the Ohio or Lima oil, which is the lightest, running from 33° to 36°, the Illinois and West Virginia, running from 30° to 33°, and a few trials of Kentucky which proved too heavy for our use. The heavier oils in cold weather flow very thick and, unless they can be heated, will not flow. In this range of oil, I have never been able to determine any great difference in heat units. As I began the use of Seger cones and the electric pyrometer in 1895, we were in a fairly good position to determine this fact, which was also confirmed by a Pennsylvania Railroad test. While I realize that we cannot claim priority in use of oil for burning clay wares I have never heard of any clay industry in this country using cones or pyrometer before 1895.

Crude oil, as it comes from the ground, generally carries considerable alkaline water, and unless care was taken by the producers, we have at times had considerable water in our cars of oil. When the oil reaches us, we always screen it ourselves to insure clean oil in our system. Insurance companies, quite properly, will not allow a gravity feed, so the oil is stored in 10,000-gallon tanks below the level of the plant. From these we pump it into a small 500-gallon service tank; and to this tank apply an air presure, which forces it to the burners. This method has been criticised on the ground that it may not give an absolutely uniform pressure at the burner. By frequently renewing the oil, the slight variation is rendered negligible. The duplex oil pump, working constantly is the method usually employed. Burning oil in a kiln is a good deal like burning the old oil lamps; adjusted just right these gave perfect combustion; but permit the least lack of this adjustment and it was simply amazing what a smoke they would make. We find that the oil has a tendency to thicken in our storage tanks and often becomes a hard proposition for the pumps to handle. While we have a duplicate pumping system, still at times we have to shut down and overhaul pumps and oil supply pipe. With our

method this causes no interruption of the firing, since we always have a four or five-hour supply under air pressure in our service tank.

With the oil at the kiln, the next question is whether you will spray with air or steam. Opinions differ, some favoring one method, some the other. We have always used air, and I believe it is by far the best. It is true that compressed air requires a special equipment while most plants have steam available, that steam is a better mechanical sprayer *per se* than air, just as a spray of steam for smoke abatement under the boiler is like a charge of shot while air does not have this effect, and that further the heat conveyed to the oil by the steam is advantageous. On the other hand, to burn the oil we must have the oxygen conveyed by the air mixed with the oil; this steam does not give us. The proper spraying can be gained by using a good burner, and we all know how hard it is to convey steam any distance without condensation. Another very important point is the danger of condensation in the kiln during the early firing. No matter what kind of clay ware is being fired, the hot kiln gases will become saturated with water vapor from the ware, when the kiln is started. With every precaution there is always danger of condensation on cold ware. This condensed water carries sulphuric acid, the source of many troubles. So, it can easily be seen that it is anything but advantageous to introduce steam into the kiln at this time. In using air, we have a perfect control of the fire at all times with the same ease in shifting from oxidizing to reducing conditions that one has in controlling the air on a bunsen burner. In our firing, to preserve our coloring oxides, we aim to maintain an oxidizing fire, and this the use of air enables us to do. One of the corporations in this country made careful comparative test of burning with air and steam. They showed a saving of 30 percent using air over the same oils burned with steam.

The next question is that of pressure. Again we have two methods, the high pressure and the low. Some systems have been devised and strong claims made for them in which the pressure used is only a question of ounces, while we are using a 24-pound pressure. Mr. Gray speaks of a 12-pound pressure; this would be classed as a high pressure system. Not to enter into discussion on

this branch of the subject I merely state that the high pressure has always seemed to me to be the better method.

We now reach the question of what burner to use. There are many different makes offered. I have tested some of these, but always found that for our conditions a burner we made ourselves is the best suited. I am not at all certain it would suit other conditions as well. It is an easy matter to test various makes until the one best suited is found. The air, oil and mixer should be separately controlled, and all parts should be easily accessible at all times. In burning oil, it must be remembered that the oil is a liquid which has first to be vaporized then gasified before actual combustion can take place. The difference in burner is largely in the ability to vaporize the oil. When a burner delivers completely vaporized oil, gasification takes place very readily, and the oil can be lit with a torch and burned with a flame reaching back almost to the burner. With poor vaporization by the burner, this is impossible, and a spray brick must be used upon which the oil coming from the burner strikes. As soon as the fire box has become sufficiently heated to maintain combustion, this spray brick can be pushed aside. When the spray brick is necessary, it is an indication at once that the burner is not functioning perfectly, and a deposit of carbon will soon be formed on the spray brick. Still, burners that have this defect may work all right when sufficient heat has been gained in the fire box. The first test of a burner, however, is whether it will burn in the open air with a little flame, not over a foot long, which in this case will reach right back to the burner. This is a very severe test which few burners will stand, and as I have said a burner should not be rejected on this ground. The next test is whether when full fire is desired the burner supplies sufficient oil properly vaporized and mixed with air to burn with a clear fire. At no time during the fire should there be any smoke. I have tested burners that started off well and would carry a kiln to say 2000°, and then fail to properly deliver sufficient oil to advance the heat above this point without going over to a reducing fire.

When we started our oil burning, we had a great deal of trouble. Burners would be going nicely then suddenly go out. The cause was at first a mystery as all oil had been screened. We found out in time that the iron pipes conveying the oil were scaling, and

this scale was cutting off the oil at the burner. We had to repeatedly blow out the whole system with steam. In time the pipes became "pickled," as oil men express it, and this trouble ceased.

With the oil burning all right, the next question and a very important one, is the proper fire brick to use in the kiln mouths. I tried practically all fire brick within reach, and even had special brick made, in my endeavors to find a brick that would stand the test of oil firing. I decided it could not be a question of excessive heat, as we just reached cone 25 in the fire boxes; still the best fire brick would melt and literally pour down the cheeks. The oil gave no ash, and there was not sufficient heat, so what could be the cause? I stated in the beginning that crude oil carried with it alkaline water. This gave me the key to the solution. The alkaline vapors formed in burning the oil were combining with the free silica in the brick. What I needed was either a basic brick or at least a neutral one and not an acid brick. At once I washed all brick with kaolin containing as little free silica as possible and found a decided advantage. The next problem was to find a fire brick made from a kaolin (not a fire clay) bounded with as little plastic clay as practical, the whole having the least possible free silica. Fortunately a brick of this character was found, and our fire brick troubles were reduced to a minimum.

In our first trials, our fire boxes were built with low arches and a fire-brick, open baffle wall. We soon found we had no trouble in completing our combustion; in fact just the opposite was true. The combustion was completed so quickly that the heat was all liberated in the fire box and grew so intense that the low arches were melted down in short order. So we took out the baffle wall and omitted the arch altogether, giving the heat every chance to get out of the fire box and up into the kiln proper. The fact that we produced a heat of cone 25 in the fire box in order to get cone 3 in the body of the kiln explains the situation. It was this condition which induced me to make the experiments previously reported to the Society, which aimed to transfer this excess heat of the mouth to the kiln by the dissociation of water vapor. This might seem to be an argument for burning with steam; but at 1000°C. if I remember correctly, only 50 percent was dissociated, the remaining 50 percent even at this heat not being dissociated.

Burning with oil requires some experience, just as burning with

coal does, and some, who have tried it have been too easily discouraged. One white-ware manufacturer told me he had put in a full equipment, and then had given it up in despair after a few trials. In another case, I saw a kiln burning with oil that had smoke pouring from fire boxes and stack—a low pressure system by the way. One could easily imagine the probable results. Mr. Gray's "greasy scum that would not wash off" was undoubtedly due to sulphuring which was entirely unnecessary. With careless burning and poorly luted saggers, we had lead glazes form lead sulphate, a very insoluble product and the cause of terrible losses to the potter. On the other hand with careful burning we can burn lead or any other glaze, to say nothing of chrome-tin pink colors, right in the open with no saggers at all.

The advantages of fuel oil are so obvious, that they need not be mentioned. As bad features, there is trouble to maintain joints tight and prevent leaks, and the fact that the rapid complete combustion liberates the heat in the fire box and heat is gained in kiln proper by convection only. I understand the Southern Pacific Railway at first abandoned the use of oil for their locomotives because they could not get fire boxes to stand the blast heat of oil burning. For crucible work this condition is ideal; but when you want the heat in the kiln and not in the fire box it is a different problem. The great objection to oil, however, is its prohibitive price.

It seems probable that anything written about oil for fuel purposes today will merely serve as history. The considerable over 100 percent increase in price for it in less than one year has brought oil to a point where its use by clay workers is out of the question. Moreover, all dealers seem to feel that no great reduction in this price is at all probable. A great deal of this grade of oil is used on roads, although I understand the state of California has abandoned the use of oil on roads after a thorough test. Marine boiler firing is taking constantly more fuel oil, and the internal combustion engine able to use as heavy an oil as fuel oil is an accomplished fact. Oil today is quoted at five cents per gallon, while producer gas plants claim to be able to compete with oil at three cents. So, if the price of oil is going to stay up as seems probable, any clay worker, it seems to me, would be very ill advised to install an oil burning plant.

THE BRICK INDUSTRIES OF EUROPE

BY G. WSON. CRONQUIST, SWEDEN

It is a rather great subject your honored Secretary has given me to read a paper about, "The Brick Industries of Europe," and I must at once say that I am not prepared, either by the needed figures and pictures or by experience, to talk over the whole subject mentioned. There are over twenty states in Europe, and it is only from about half of them, and at most the northern ones, that my experience is taken, namely, Sweden, Norway, Denmark, Finland (Russia), Germany, Austria Hungary, Italy, Switzerland, Holland and England. A superficial chat about some things used in Europe but, perhaps, not here in brick and tile manufacturing is all that I can give, if you have patience to listen and if you will kindly beforehand excuse my poor English.

Raw Materials. The raw material used for brick making is the glacial surface clay, sometimes hard and containing limestone, often plastic and too wet to be used direct. Most of this plastic clay must be mixed with sand to avoid cracking and to decrease the shrinkage. The splendid shale for red burned, crude clay products that you have in the United States is very rare in the Northern part of Europe. There are, however, some shales in the south of Sweden and in Germany; but they are higher in alumina and are poorer in iron oxide than the shales mentioned above. They are fire clays, some of them among the very best known, and burn from cream yellow to a brown color.

Manufacture of Fire Brick in Sweden. Time will not allow me to compare the different manufacturing methods of making fire bricks in the different states. There is, however, in the Swedish process of manufacturing fire brick from shale, an interesting point. Some of the shale contains coal thoroughly mixed by nature. This shale is laid in high heaps and lighted, burning in some months by its own coal to a very good gray. There are, however, other shales containing a little more coal, and this is used in gas production, whence we get gas for burning the fire bricks, vitrified brick, face brick, etc. The ashes from the gas-producer shales are used as grog for vitrified bricks or ground and mixed with some 5 percent

of milk of lime and pressed into brick. The ashes are hydrated and hardened in three to five weeks into a perfect brick for inside use, which is as light as wood and can be nailed like wood.

Common Brick Manufacture. Common brick manufacturing is done entirely by the soft-mud, wire-cut process. Only in a few places in West Germany and in some places in England, where there are shales similar to yours, is the dry-press process used. The soft-mud process, formerly the hand-made process, seems now coming back as a result of the wishes of the architect to get rid of the wire-cut, soft-mud bricks with their smooth surface. But hand molders are now rare and expensive, which makes us have machines for making "hand moulded bricks," which are either water or sand molded.

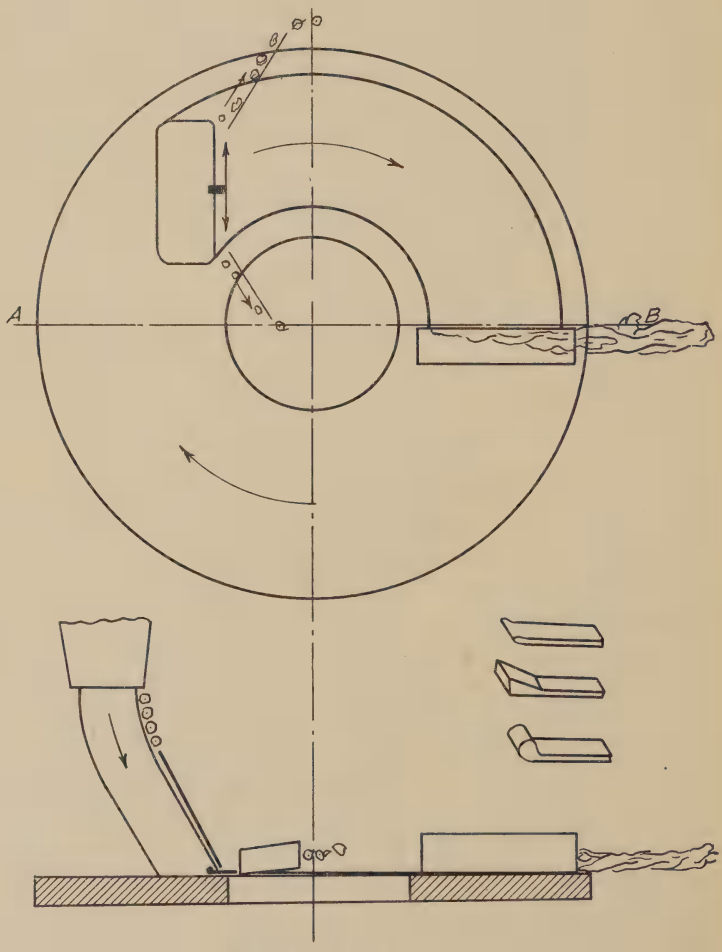
If we now follow along the process for making bricks or tiles, we have:

1. Preparing and mixing of clay.
2. Pressing, forming.
3. Transportation to dryer.
4. Transportation to kiln.
5. Burning.

Preparation and Mixing of the Clay. The surface clay is often plastic and mixed with gravel, sand or limestone. The last mentioned, as we know, is a bad thing inside the brick and in grains more than two millimeters in diameter. For the better classes of wares, roofing tiles, hollow blocks etc., it is good practice to weather the clay one winter, and, after mixing, store it twenty to thirty days to get even distribution of moisture through the whole mass, increase the plasticity and decrease cracking. It is necessary to clean the surface clays from impurities, such as gravel, rock pieces and limestone, more necessary than for the shales that you grind. The wash mills are still used and are the best way at many roofing-tile plants. Different kinds of rolls are constructed and used and other systems, as, separators, Bohn's and Diesener's clay cleaners, etc.

As the principles of the Diesener machine does not seem to be wel known in this country, it may perhaps interest you to see a sketch of it. Figure 1 shows the main points. Pressed at a certain angle, depending on the property of the clay, against the

Trans. Am. Cer. Soc. Vol. XV Fig. 1 Cronquist



SECTION A–B

DIESENER CLAY CLEANER

revolving cast iron discs, six to ten inches in diameter, is the column of unpurified clay mixture. Between a quarter inch sheet-iron plate and the revolving disc is a slit that can be regulated. The

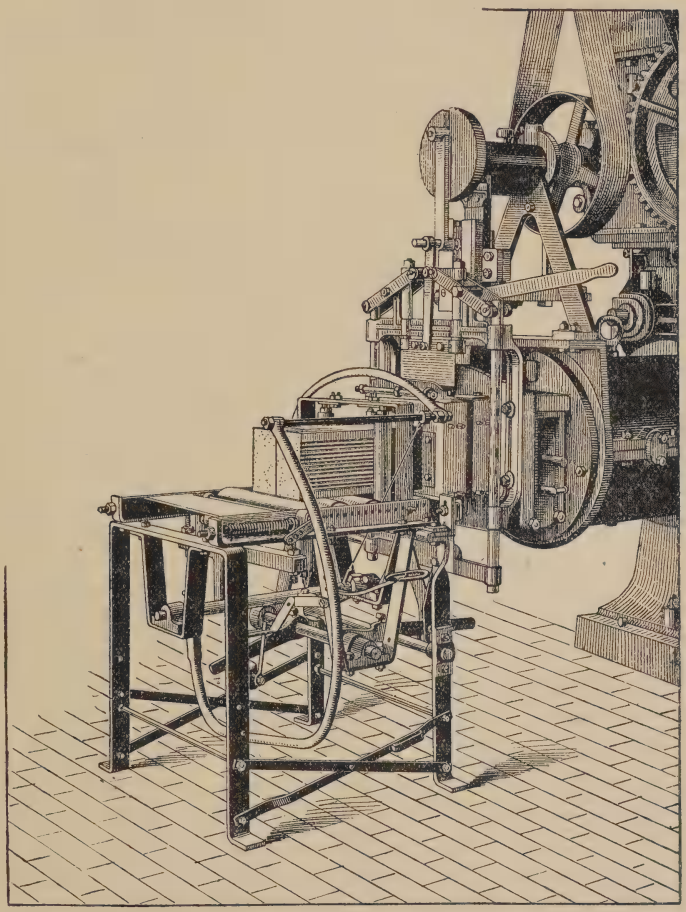


Fig. 2

clay strikes the disc and passes the slot. The gravel and limestone pieces, however, stop against the above mentioned sheet-iron plate. A knife, moving backward and forward in the slot, cleans

away the rock pieces and lets them drop down on inclined grooves. The purified clay is scraped off from the disc by a knife and drops from there into the press. The capacity of this machine is not great, 5,000 to 10,000 bricks a day with normal speed and narrow slot (one-sixteenth inch); but it works very well, is especially suitable for roofing tile manufacturing and does not require much power, two to three horse power.

The mixture of sand (grog) and clay passes through a pug mill and goes into the press, of which we have many of different constructions. As we in Europe do not work with such stiff mud as is used here, the machines we have are not so heavy and strongly built. My experience with some clays is that they dry slower stiff than soft and yet there is of course less water in the stiff mass. It probably depends on the smooth, tight surface made by the press which prevents the entrance of the air.

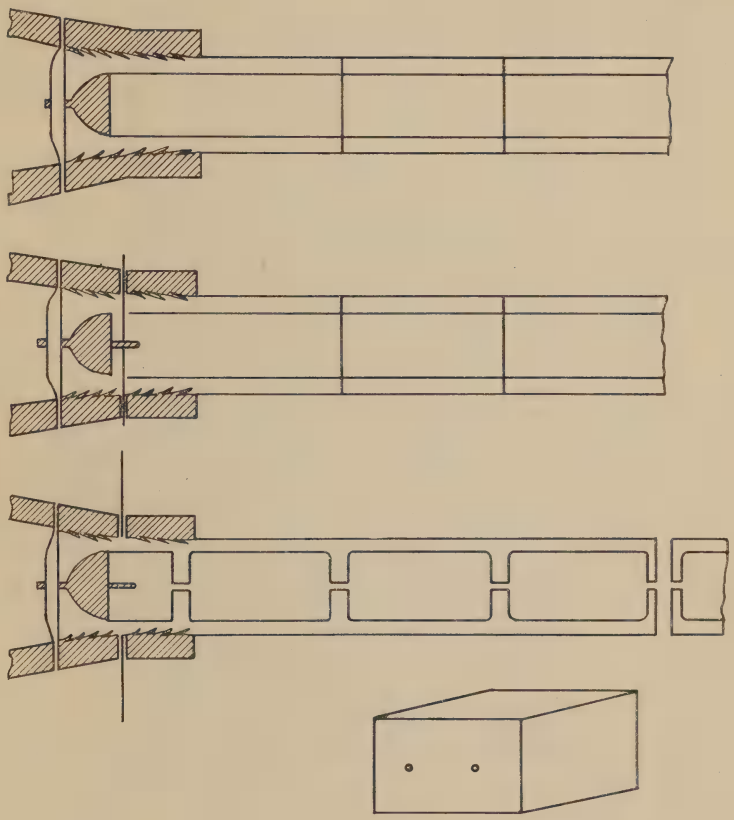
Figure 2 shows how we fasten the wire for cutting bricks. That is a nice thing for small yards since you can change wires while running.

One of the most interesting inventions for forming tile by the auger machine is the making of hollow blocks with closed ends. The inventor is a German tile manufacturer. Figure 3 shows the principle. Cut 1, Figure 3, shows a section of the die for hollow tiles. Cut 2, Figure 3, shows how two dampers are filled and closed vertically through the die. The clay, pressed from behind must fill the space between the core and dampers. Cut 3, Figure 3, shows the result of intermittent shutting and opening of the dampers, i.e., vertical walls are made. Small iron pegs, one-fourth inch in diameter, attached at the front end of the cores, serve as stops for the dampers and make small holes in the vertical wall. These holes serve as air passages in forming and especially in drying and burning. If it were not for these the blocks would crack very easily. By cutting the column we get a hollow tile closed at both ends. The cut at the bottom of Figure 3 shows such a tile. Of course, the cutting and operating of the dampers are connected together.

The system has succeeded well on the European Continent. The advantages of such tile are evident: less weight, higher crushing strength, better insulation and less consumption of mortar in building walls. The tiles are used especially for reinforced roofs

made by concrete casting systems, but are also used to a large extent for insulation walls—outside against temperature, inside against noise.

Trans. Am. Cer. Soc. Vol. XV Fig. 3 *Cronquist*

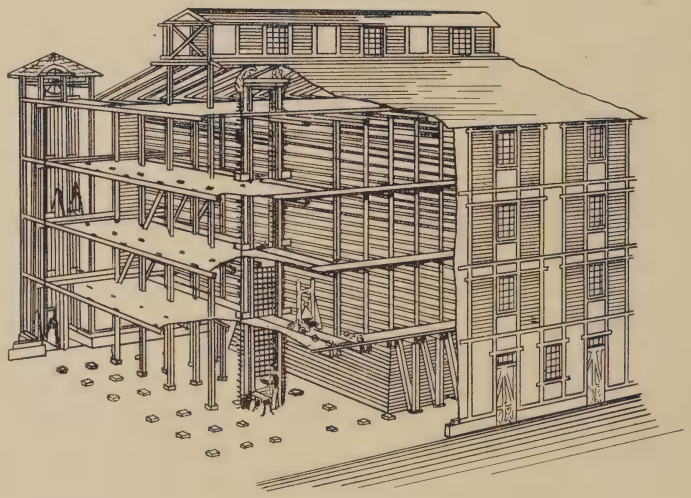


Transportation to the Dryer. In ninety percent of all brick yards known to me in Europe, open dryers are used, more or less combined with the use of waste heat from the kilns—radiation or heat from the cooling bricks.

For carrying roofing tiles from the press to the dryer, we use the truck system because we employ a great many boys, girls, and women in our factories. The trucks have ordinary cycle wheels with rubber tires and ball-bearing axles. It is very easy for a boy or girl to wheel thirty-five interlocking tiles on such a truck.

The greater part of the larger brick yards in Sweden are now fitted with the Svedala transportation system for bricks. Figure 4 shows a perspective view of such a brick factory. You can see the men taking the bricks from the cutting table to the chain elevator on which the pallets rest. When a block of ten pallets,

Trans. Am. Cer. Soc. Vol. XV Fig. 4 Cronquist



containing 10 or 12 bricks each, has come to the right floor level, the elevator stops itself, and an automatic revolving truck is used to take them from the elevator. The pallets are lifted free from the elevator by lowering the lever shown in illustration 5. The truck is moved on a transfer car alongside the dryer and emptied by raising the lever. Figure 5 shows the method of filling the dryer from the transfer. By this system we fill with brick the whole space above the kilns.

We use the radiated heat from the kilns for drying, together with the open air of course. The bricks are dried in from one to three weeks. They are then taken down on a chain elevator, similar to the one described above. The bricks, still on the pallets,

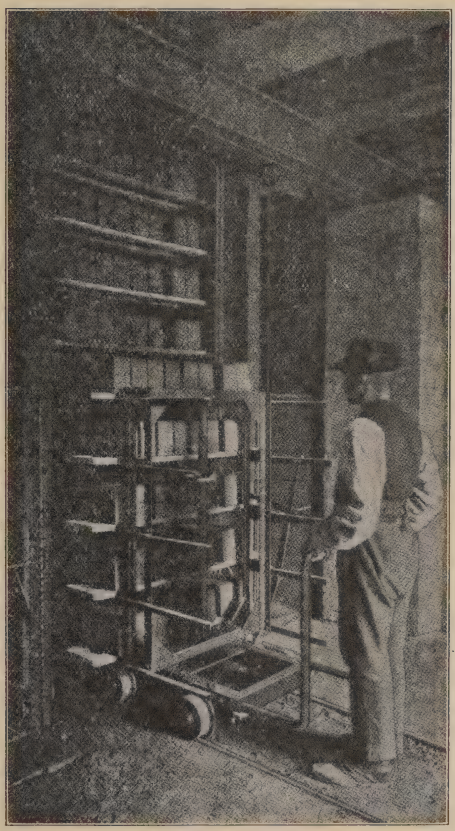


Fig. 5

are taken into the kilns by a revolving truck similar to the one already described, except that it is loaded on both sides and carries five pallets to a side. This low truck is used in order to enable it to enter the low doors of the kilns. By this system, we are able

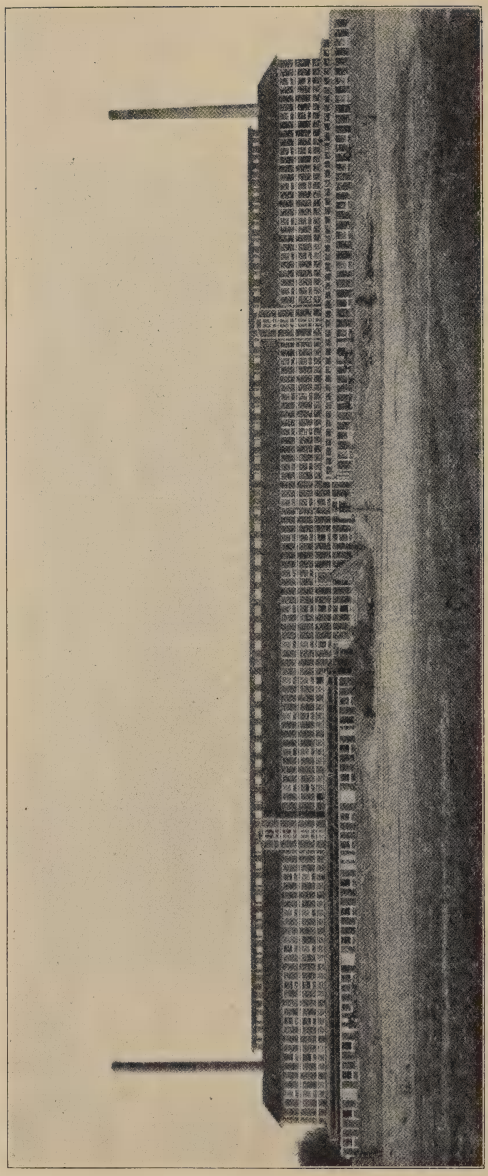


Fig. 6

to move the bricks from the cutting table to the setting gang in the kiln without handling.

Figure 6 gives a view of a Swedish brick yard built on this system, containing two continuous kilns under the same roof and producing about fifteen million bricks a year. The heat radiated from the continuous kilns is not enough to run the yards the whole year round. The plant must therefore shut down about the fifteenth of October and start again in May. Furthermore the clay would freeze in the pit and on the way to the yards. This is the reason the capacity of such a large factory is not greater. The size of the brick is another factor. The common size of our bricks is three by six by twelve inches; they have about twice as much volume as your bricks, and of course they dry much more slowly.

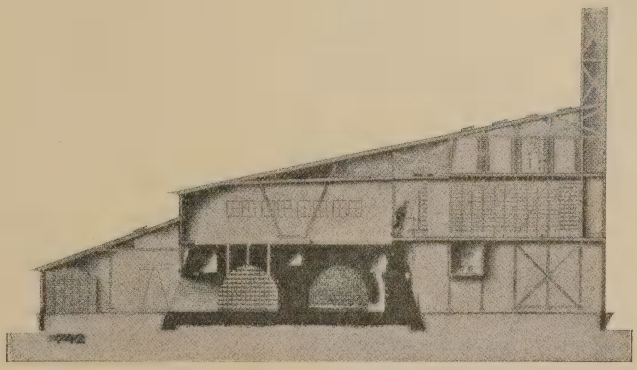


Fig. 7

Another system for drying is shown in Figure 7. Here the dryer is not above the kiln but parallel with it and supported above the ground by pillars. The radiated heat from the kiln is drawn to the dryer by aid of wooden stacks, such as you use at the end of your steam dryers. The bricks are set in the dryer by an automatic truck similar to the one described above. A good practice employed at this plant is to accumulate the waste steam from the engine in daytime in the form of hot water and to use this for drying brick at night by allowing it to circulate through pipes below the dryer. Another advantage of this system is that the weight of the dryer

and bricks is not supported by the kiln, which, of course, expands and contracts on heating and cooling. This system is especially suited to the drying of roofing tile.

Another system for the same purpose is the Rudolph Witte dryer. The roofing tiles, coming from the press room on a chain conveyer, are distributed, lying on the pallets, into the upper part of the dryer. This is built with an inclination that causes the pallets to slide down when the dried tiles are taken away from the lower end. The principle here is that the tiles are sliding down in a direction opposite to that of the warm, dry air coming from the kiln below. Mr. Witte draws the waste heat from the cooling bricks through great iron tubes and forces it into the lower end of the dryer. In some large factories the radiated heat from the kiln and the waste heat from the bricks is not enough to dry all the material. They use a stove that seems to be cheap in operation and which produces 3,000 cubic meters of hot air a minute.

Burning. Except in England, the discontinuous kilns, round, down and up draft, are not be to found much in Europe. Instead of that, the well known continuous tunnel kiln, Hoffman's fine invention, is used in hundreds of different constructions. If you compare the prices of coal here and, for instance, in Sweden, and use, not dollars and crowns—they are not commensurable—but the worth of a workman's day work, you will find that you get a ton of coal for half to one and a half day's work here, but we must take four to seven days' work in Sweden for one ton of coal. We have to pay an average of five times as much for the same amount of heat, using the method of calculation mentioned above. It is, of course, then clear that people must be more careful here to save labor, and in Europe to save coal. That is the reason why the coal-saving kiln, the continuous one, is used everywhere in Europe for any kind of crude clay products. The continuous kilns are well known to all of you, of course, therefore, we had better pick out some interesting systems not so common.

Figure 8 shows, for instance, a plan of the Muhlacher Brick and Tile Factory in Bavaria, built by the German kiln and drying expert, Bulher in Constauz. The three kilns are all built on the same principle, zig-zag kilns. Mr. Bulher gets by this construction a very large burning channel on the same surface as the ordinary

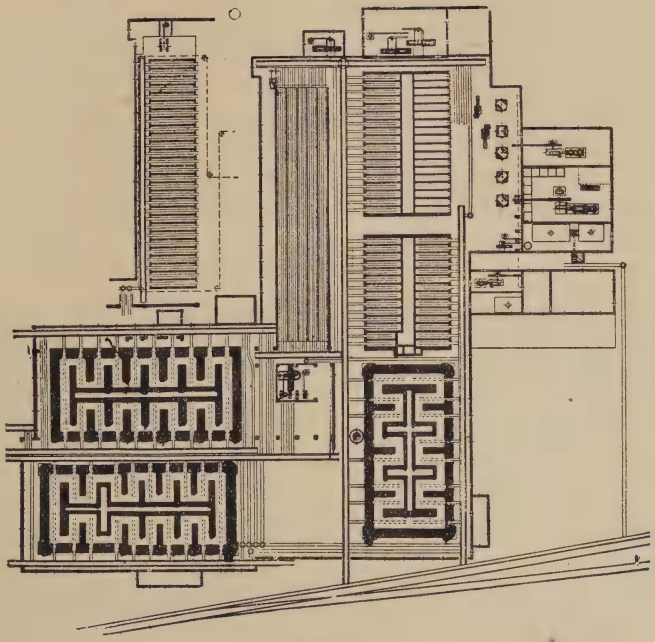


Fig. 8

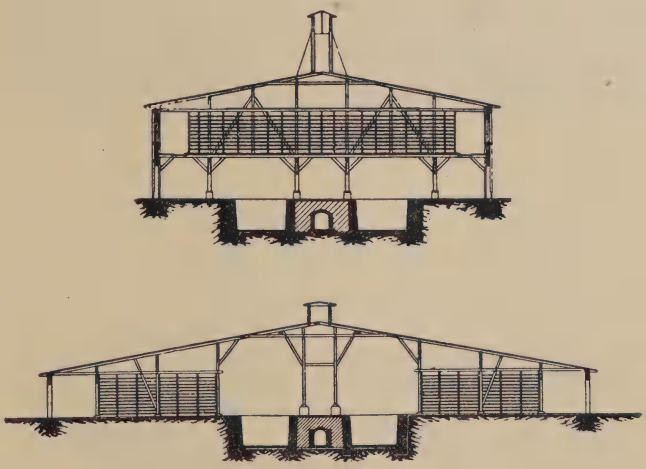


Fig. 9

tunnel kiln. He burns his kilns very fast, advancing the fire 100 feet a day (24 hours) is not unusual, and must use large fans for getting draft enough. The setting is done through the doors, and several chambers can be set at the same time. The product of this factory is thirty million first class, red-burning, roofing tiles a year; and it is supposed to be the largest and best equipped roofing-tile factory on the European Continent. The tiles are dried by waste heat from the cooling bricks in the chamber dryer (to the right and left on the picture); and the common bricks are dried by com-

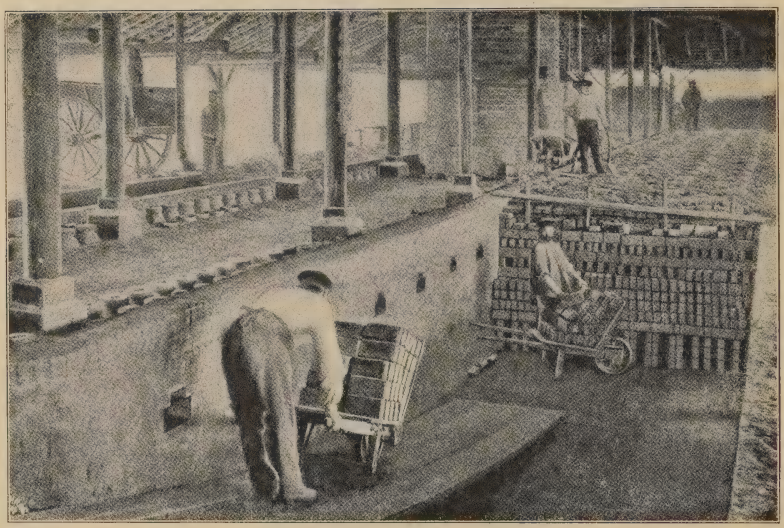


Fig. 10

bustion gases in tunnel kilns on cars coming direct from the press. The kilns are heated from the top by dropping the coal on the brick, as usual in continuous kilns. The feeding, however, is more frequent here, every five minutes.

An old system for continuous kilns, cheap to build and, if made good, cheap to operate, is the tunnel kiln built under ground. The first ones were constructed, I think, by Otto Boch in Berlin about fifteen years ago and are yet in good condition. Figure 9 shows the principles of this system of kilns. The upper one is a section of

a yard with the dryer above the kiln; the lower one with the dryer on both sides of the kiln. For water smoking you have to put in another flue. Many yards, especially for hand moulded brick, are using these kilns, but they have proved to be good ovens for tiles of different kinds, even for glazed ware.

Figure 10 shows the way it is set and covered. This one has flues for water smoking (entrances shown on the wall). Combined with the electrical setting machine used in this country, you can hardly get a cheaper way for getting your bricks set, burned and unloaded. There are some methods used in Europe for making bricks that perhaps are not yet adopted here; but may be altered, of course, to suit the raw materials and local circumstances.

If this talk may be of any use to the American clay manufacturers who have shown me so much courtesy during my visit, I will be very much pleased.

GLASS STANDARDS: A NECESSITY

BY ALEXANDER SILVERMAN, PITTSBURGH, PA.

Much has been written about the chemistry and technology of glass, but, aside from the study of optical properties, little has been published regarding standards to which glass should conform for specific uses. In very recent years manufacturers of reflectors have begun to realize the necessity of photometric tests so as to permit of a proper distribution of light and enable the engineer to figure the location of units for areas to be illuminated. One manufacturer of lantern globes has each globe dropped a certain distance on to a pine plank and thus establishes a shock test. The globes are also placed over burners and, when hot, sprayed with cold water to determine whether they will resist the sudden change of temperature. Both tests are important, especially the latter, for lanterns and lenses used as signals in railroad service. Chemical glassware has probably been subjected to more tests than any other type. Gauge tubes and bottles for carbonated beverages have been subjected to pressure tests. And so one reads now and then of others. A few abstracts from the journals of the past ten years may serve as examples of what has been written.

Percy A. Walker in contribution No. 58 of the Bureau of Chemistry of the United States Department of Agriculture gives the following tests for chemical glassware, which were printed in the April, 1905, number of the *Journal of the American Chemical Society*.

Preliminary treatment. Wash article in pure water, fill, let stand at 20 to 25°C. for 24 hours.

Mechanical tests. (1) Fill beaker one-fourth with 10 percent solution of sodium chloride, evaporate to dryness on steam table, dissolve residue and repeat evaporation four times, heating beaker six hours after last evaporation. Wash and examine for cracks. (2) Fill 400 to 600 cc. beakers or flask one-half with pure water at 20°C. Place on platinum triangle over open flame 12 cm. high and 8 cm. from bottom of vessel. (3) Have vessel at 20°C. and pour boiling water into it.

Solubility tests. (5) Dry and weigh vessel, add 100 cc. of 2 percent sodium carbonate solution, cover, boil twenty minutes, empty, wash with water, hydrochloric acid, and again with water, dry and weigh. For beakers

return sodium carbonate solution and evaporate to dryness, uncovered, on steam table. (6) Repeat using 2 percent potassium hydroxide solution. (7) Repeat, using 4 percent ammonium carbonate solution. (8) Introduce 100 cc. of neutral water, cover with platinum dish, heat 48 hours on steam table, make up to 150 cc. Place 100 cc. in glass stoppered bottle, add 20 cc. ethereal solution of iodeosin (0.002 g. per 1000 cc.) and titrate with fiftieth normal sulphuric acid solution to disappearance of pink color. (9) Fill vessel with pure water, let stand 20 to 25° for 24 hours and determine electrical conductivity.

Mr. Walker concludes that cracks resulting from test No. 1 indicate poor glass, that No. 1 and No. 8 combined give an excellent idea of the relative merits of vessels tested, and that more than 0.4 cc. of fiftieth normal sulphuric acid in test No. 8 means a very poor glass. Alkali-lime-silicate glasses on the American market at that time were found to be of inferior quality.

F. Mylius in the *Zeitschrift für Anorganische Chemie*, volume 55, page 233, in an article, entitled "Eosin and Iodeosin Reaction on Surfaces Prepared by Breaking," states that the reaction should cease after one minute in glasses desirable for laboratory ware, that it may last from one minute to one day as a comparative weathering test sufficient for cut and polished objectives made of the lighter optical glasses, but that if the reaction is not passive after one day the glass should be rejected. He agrees with Follens, Landolt, Stock, and Heineman in the claim that an unfractured surface is not permeable to iodine vapors.

Mylius, together with E. Graschuff, same journal, volume 55, page 101, "Alteration of Glass Containing Water," claims that glass of the type mentioned, when heated under reduced pressure, becomes opaque and cracks or scales at 400°C. due to absorbed water. If glass is heated gradually, this may not happen.

C. Jacobson, in the *Apotheker Zeitung*, volume 25, page 262, writes on "Alkalinity of Medicinal Glassware" and gives quantities of hundredth normal hydrochloric acid required to neutralize morphine precipitated from a hydrochloride solution contained in various bottles.

F. Mylius and E. Graschuff in *Sprechsaal*, volume 43, page 217, tell how the etching of a small exposed part of a paraffined surface will furnish enough material for the detection and sufficiently quantitative determination of SiO_2, B_2O_3, CaO, BaO, PbO, ZnO, Sb_2O_3,

MgO, K_2O and Na_2O. They claim that the type of glass can be recognized in this way.

Regarding the effect of sunlight on colorless glasses, R. A. Gortner writes that on exposure for from one to eleven months all specimens containing manganese, except Jena glass, turn violet and that specimens free from manganese did not show this change.

E. Rutherford in the *Proceedings of the Manchester Literary and Philosophical Society*, volume 54, number 5, states that glass exposed to alpha rays of radium emanations turned purple, and that the color zone extended 0.04 mm. under the surface exposed. W. A. Douglas Rudge, *Nature*, volume 78, page 151, also found that glass exposed to radium salts turned purple but that British South-African sunlight subsequently almost completely decolorized it.

Robert L. Frink, *Transactions of the American Ceramic Society*, volume 12, page 585, in an article entitled "Requisite Properties of Glass for Mechanical Manipulation" recommends the use of a microscope, magnification about twenty diameters, fitted with polarizer and analyser and a selenite plate, red of the first order, for examination of glass to show strains and heterogeneity.

H. Hovestadt, in his book *Jena Glass and its Scientific and Industrial Applications*, in addition to giving optical properties, speaks at length on mechanical and thermal properties of glass and the chemical behavior of glass surfaces.

Other data might be cited, but the question would still arise, "Have we a set of standards which can be applied in every day practice?" Our common American proverb, "Accidents will happen" does not state that precaution should not be taken to prevent them. Tungsten lamps may have a shortened life because of the moisture content of glass in the bulbs. Lamp and gas chimneys are cracking without apparent cause. Cased ware is constantly breaking because the two glasses employed in its manufacture do not have the same coefficient of expansion or even closely approximate it. Window glass frequently breaks at temperatures far below the boiling point of water. Medicinal and food products sometimes undergo a change because of the composition of the glass containers. Bottles containing beverages carbonated under high pressure are apt to burst. One reads now and then of a plate glass window which is crushed by a wind storm when others

all around it are in good condition. Cases are on record where a break occurred without an apparent cause. Today plate glass, transparent, opal, or black, is pretty generally used for bath-room fixtures or for shelving for display purposes in shops. Pressed ware, especially bowls for semi-indirect lighting, is constantly being made larger, some manufacturers producing articles thirty or more inches in diameter. Containing large masses of glass, they are naturally very heavy. It seems all important that the manufacturer should take every possible precaution in the production of such articles to insure the user against accident through some fault in the article furnished. The composition and mechanical properties of a glass are exceedingly important. Too much care cannot be bestowed on its "annealing" or, as a prominent glass specialist recently remarked, "its uniform cooling."

Precautions are taken. Certain plate manufacturers have imbedded wire to protect the user from accident by flying pieces. One inventor has placed a solution of celluloid between two plates and by subsequent pressure glued them together. The celluloid interlining, causing the glass plates to adhere firmly and being tough, holds the splintered mass, and we have what is called an "unsmashable" glass. It is hardly likely that all glassware can be so treated as to make it safe; the artistic must also be considered. Mechanical tests can, however, be made, thus lessening the element of danger.

Color and composition should be standardized. Ruby glass has any color from the pure pigeon-blood of the gold product to the possible dirty brown of a copper glass. Opal glasses vary from a dense white to a homely fiery product or to the more recent translucent and semi-translucent types in which the fire no longer shows. The transmission and reflection of light by opal glasses covers a wide range, and some of them are almost useless. The classification of transparent colorless glasses is important. A glass branded "Lead Flint" or "Lead Glass" should certainly contain enough "lead" to justify the name, and not large quantities of "lime" or other substitutes. It would seem only fair that the glass contain more than 50 percent PbO (by molecular equivalence) in the "base" materials entering the batch, excluding the alkali.

The use of glass is constantly increasing. Our responsibility

must keep the pace. A series of standards would help the conscientious manufacturer as well as the purchaser, and the writer therefore respectfully recommends that the American Ceramic Society appoint a committee of men, representatives of the various branches of the industry, to consider the possibility and advisability of establishing standards. The United States Bureau of Standards would, in all probability, gladly coöperate.

The writer has only occasionally suggested standards in this article, because he feels that the committee above mentioned can do so far more comprehendingly. It is sincerely hoped that the American Ceramic Society will take immediate steps in the matter.

Department of Chemistry,
University of Pittsburgh.

DISCUSSION

Mr. Frink: Dr. Silverman I think has started something that's a pretty big proposition, but it is all important to the glass manufacturer, and not only to the glass manufacturer but to all users of glass. Recently I made a series of investigations of 168 beer bottles. The purpose of the investigation was to determine the cause of beer deteriorating, or flattening, as it is called. I found a great many of these bottles to be so high in alkali that beer which was very lively before bottling became spoiled and absolutely no good to drink inside of four hours after it was bottled.

I believe there is hardly a chemist who purchases chemical materials in any quantity, who has not seen his ammonia bottles covered with a white coating on the inside. I doubt if there is any housewife who has allowed the water from her well or from the hydrant to be placed in a glass vessel, and allowed it to stand for any length of time, without noticing a coating on the inside, many times attributed to the water, but I dare say more often due to the glass. I doubt if there is a brakeman or railroad man but has done some fine stunts in elocution at times when he found his lantern globes spotted by reason of the rain falling on them. I do not believe there is a glass article made but what, at some time, in some factory, it is produced from glass so soluble that anything in a liquid form brought in contact with or placed in it is contaminated. For that reason,

standardization, as Dr. Silverman speaks of it, is very important. The other conditions he speaks of, I agree with him, are important but I do not think they are essential as they are in those situations where we have to rely upon glass utensils as receptacles for food and the like.

I am informed that one of our large bottling concerns in this country a few years ago was brought before the Federal Food Commission because of catsup spoiling and their introducing something as a coloring matter which they should not introduce. This they strongly denied and were correct in their contention. It was not the material they used for coloring, but a chemical reaction which took place subsequent to the bottling that caused this condition, and the reaction was due to the bottle. Strange to say, one of the largest chemical manufacturers in this country, only a short time ago, was very much put out because they had bottled and stored a considerable quantity of ammonia which was a complete loss by reason of the bottles which they manufactured. They were chemical people, and yet they did not employ a chemist to standardize their materials and get their vats and glass in proper condition. And so it goes.

Now there are one or two little incidents and notes I have made in regard to standardization. Dr. Silverman looked at me rather directly when he spoke of the iodine test as being no good. He also spoke of the solubility test as being of no value until the piece was fractured. I think that explains why the iodine test is of no value and I have found, by investigations made a number of years ago, that the strength of glass largely depends upon its surface. In some instances I found that the removal of a three thousandth of an inch from the outside of a pane of window glass reduced its strength close to 20 percent. For some reason or other, this exterior surface seems to take a closer molecular arrangement or hardening effect, which is analogous to a case-hardening; and therefore, unless that is removed, the iodine test or anything else, outside possibly of caustic alkali or hydrofluoric acid, would not affect it. If that surface is first removed by hydrofluoric acid and then subjected to the iodine test, I think there are but few glasses which will not show traces of iodine penetration.

As to the acid test and its use, I am using that today in making

these beer bottle experiments and determinations. In that test, I rinse the bottle inside with hydro-fluoric acid and then, after washing that out completely, until I got no acid reaction, I fill the bottle with distilled water, allow it to stand for a certain period of time and make my determination.

Dr. Silverman spoke of the plate glass window blowing in. I had occasion, some five or six years ago, to try to account for two large windows in Cleveland, Ohio, blowing in. There was quite a heavy storm, and I conceived the idea of taking a reflector and projecting a beam of light by the reflector through a nicol prism, through a diverging lens, so it would cover a large part of the window. Then, by getting back into the store and taking another lens arrangement and nicol prism, interposing a plate of selenite between them, I found that the window, was covered with strains. The strains were so great that the window was nearly white, and that would mean that it was up almost to the rupturing point. It was only a short time after that the glass really did crack, and in several windows that I examined in that manner I found none but what showed considerable strain in various sections.

Now as to the spray test as a standard, I am afraid that is somewhat of a fallacy. If you take nearly any glass article, I don't care what it may be, heat it to a proper temperature, and it is homogeneous in its structure, you can apply all the spray you wish, and I doubt if you will crack it, or you may touch a piece of ice to it or run a stream of water down one side of it and it might not crack. You might try a thousand of them and perhaps not get over a few of them that would crack. On the other hand, if that same article was not homogeneous, it would break under identically the same conditions. If the strains should be introduced by lamination and some portion of that lamination came to the surface and you happened to touch your ice to that particular point, it would be almost sure to break. I have seen cylinders of glass, 22 to 24 feet long and, due to a leak in the roof, a stream of water running down one side of the cylinder and causing no damage; and I have seen snow blow in on the cylinders and they did not break. On the other hand, I have seen them break in a million pieces. Conditions vary to such an extent, that I think such a test would be very unreliable.

As to the use of the acid and ammonia test, I have read a good

many articles on this test made by various people by putting the glass in acid or filling the articles with acid or with ammonia and then making the test. I agree with Dr. Silverman in his remarks that none of these seem to get anything like important or concordant results. Distilled water is the only thing, and that must be boiled, I believe, in order to get results.

Speaking of the absoption of glass, in Lancaster we have a little factory where they make projecting lenses for moving picture machines and automobiles. They delivered a great many lenses four inches in diameter, to some lantern people, and the lenses were returned with the report that they were absolutely no good; they couldn't use them at all, they were frosted. The president of the company brought some of them over to my laboratory, and I saw they were frosted. I went over to a picture show in town, taking over a couple of lenses put them in the lanterns, and inside of thirty minutes the screen was so dull that you could hardly see the picture. I took the lens out and found it was frosted over completely. I took the lens to the factory, put it on the polishing machine, polished it and put it back into the lantern, and it ran three months without any perceptible frost. We found, that in the grinding of the lenses, they had absorbed sufficient water for the alkali be become hydrated; then when the lens was put into the lantern, it effloresced, but when it was dry-polished it gave no trouble. I have recently found a bottle glass containing 28½ per-cent of soda and only 2 percent of lime and 1 percent of magnesia and 2 per cent of alumina, which was so soluble that if left in the water long enough it would completely dissolve or disintegrate. It was found that after remaining a short time in water a scale would form which could be removed by very little agitation.

Prof. Silverman: There are a number of Mr. Frink's remarks about which I should like to speak. In the first place, he doesn't seem to agree with me in the matter of the spray test. I think that for lantern globes and signals, it is the only fair test you can make, because they are exposed to all kinds of weather, are struck by snow and rain and are subject to cold blasts of air. The tests should correspond as nearly as possible to the natural conditions to which globes are exposed. You cannot reproduce all of the natural conditions in the factory, but you can at least approximate

them. It occurred to me that a continuous chain arrangement of lanterns, in which the globes could be placed and sprayed when they reached the highest temperature, might at least eliminate a good bit of trouble. It would be a factory precaution which would increase the price of the lantern globe; but that increased price would be justified, if the railroads were assured of greater safety.

Regarding the use of soda solutions for the testing of chemical glassware, I think Mr. Frink made a statement that left an impression which he did not want to leave. He hardly wants to say that a glass which was attacked by soda or acids should not be condemned for chemical purposes.

Mr. Frink: Perhaps I did leave a wrong impression. I meant, as a means of standardizing for all conditions and for a scientific or practical determination of solubility, that the soda and acid test would be superior to the spray test. As to the spray test, I still cannot say that I believe that would be a very good standard, although it would perhaps in part distinguish between that which is good and that which is bad. Nevertheless, if that lantern globe which you sent out under the spray test happened to be lying at a certain angle on a brick and a flame came up and struck one portion of that globe a little more than some other, the spray test would not amount to much.

Prof. Silverman: But we are not supposing they are going to set them up at an angle on bricks and have the flames strike them.

As to the iodine test, the glass was placed in a tube, which was sealed and subjected to a high temperature for a long period of time to give the iodine every opportunity of penetrating. The statement Mr. Frink made is probably correct as to case hardening preventing the iodine from penetrating the surface.

Mr. Frink: That brings up a subject which I will present to the Society. In the manufacture of window glass by the machine process, we make our glass substantially a tenth of an inch and an eighth of an inch thick. We ladle about 300 pounds into a pot or vessel and draw the cylinder up from the surface of the glass in this vessel. The conditions are substantially always the same. We will assume that the alumina in the glass is uniform and if a sample is crushed and analyzed, the alumina content is 2 percent. In the

single strength, the alumina found on the first three thousandths of an inch of the glass etched off will be probably 1.7 percent; but, if you should draw double thick of that same glass from the same pot, ladled in the same way, made from the same batch and same tank, and at the same hour, at the same temperature, the alumina in the first three thousandths of an inch of that glass may be 3 percent while in the center it will be only 1 percent. What causes the alumina to come to the surface is what I should like to know. I do not want to be understood that these figures or their ratios always prevail, they are exaggerations given to illustrate that alumina is always higher at the surface than in the center of the glass, and that apparently the thicker the glass the more alumina comes to the surface.

A STUDY OF THE RELATIONS BETWEEN FUSIBILITY AND HEAT RANGE IN GLAZES

BY HOMER F. STALEY, OHIO STATE UNIVERSITY

INTRODUCTION

It is well known that glazes of any one type vary greatly in the length of their heat ranges. Some glazes are serviceable over a range of only a couple of cones while others, of very similar composition, are good over a wide variation of temperatures. The object of this investigation was to make a systematic study of the variation of heat range in one type of glazes and to attempt to correlate this variation with some of the other properties of the glazes.

EXPERIMENTAL

The Glazes Studied. In order to have the problem as free as possible from needless complications, it seemed best to study the most simple type of glaze, i. e., the glossy raw lead glazes. The glazes were made from the materials ordinarily used in factory practice; potash feldspar, red lead, whiting, kaolin and flint. In accordance with the general knowledge that this is a favorable ratio for use in bright raw lead glazes, an oxygen ratio of 1: 2 was maintained throughout the entire series. The variations in composition of the six base glazes possible under these restrictions are given in tabular form below.

GLAZE	K_2O	PbO	CaO	Al_2O_3 and SiO_2
A	high	high	low	high
B	high	low	high	high
C	low	high	low	low
D	low	low	high	low
E	low	high	low	high
F	low	low	high	high

In order to avoid dealing with inconsequential variations of composition, one tenth of an equivalent of RO or R_2O_3 was taken as the unit of variation. The compositions of the six base glazes and

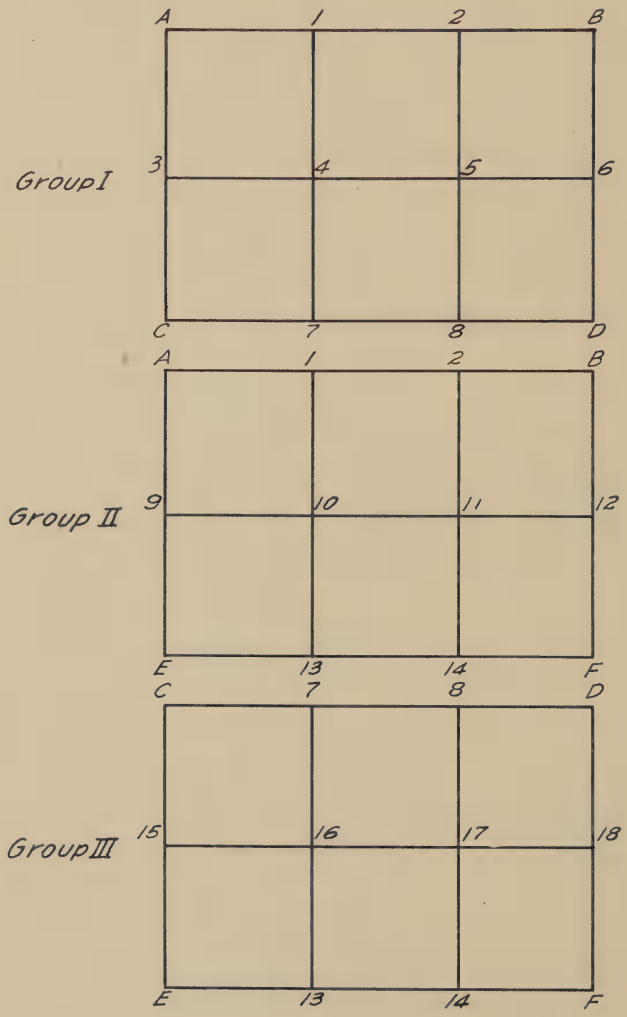
all the possible blends between these on the above basis are given in Table 1.

TABLE I

GLAZE	EMPIRICAL FORMULAE					BATCH WEIGHTS				
	K_2O	PbO	CaO	Al_2O_3	SiO_2	Potash feldspar	White lead	Whiting	Flint	China clay
A	0.30	0.70	0.0	0.30	1.90	167	180	0	6	.....
1	0.30	0.60	0.10	0.30	1.90	167	155	10	6	.....
2	0.30	0.50	0.20	0.30	1.90	167	129	20	6	.....
B	0.30	0.40	0.30	0.30	1.90	167	103	30	6	.....
3	0.20	0.80	0.0	0.20	1.60	111	206	0	24	.....
4	0.20	0.70	0.10	0.20	1.60	111	180	10	24	.....
5	0.20	0.60	0.20	0.20	1.60	111	155	20	24	.....
6	0.20	0.50	0.30	0.20	1.60	111	129	30	24	.....
C	0.10	0.90	0.0	0.10	1.30	56	232	0	42	.....
7	0.10	0.80	0.10	0.10	1.30	56	206	10	42	.....
8	0.10	0.70	0.20	0.10	1.30	56	180	20	42	.....
D	0.10	0.60	0.30	0.10	1.30	56	155	30	42	.....
9	0.20	0.80	0.0	0.30	1.90	111	206	0	30	26
10	0.20	0.70	0.10	0.30	1.90	111	180	10	30	26
11	0.20	0.60	0.20	0.30	1.90	111	155	20	30	26
12	0.20	0.50	0.30	0.30	1.90	111	129	30	30	26
E	0.10	0.90	0.0	0.30	1.90	56	232	0	54	52
13	0.10	0.80	0.10	0.30	1.90	56	206	10	54	52
14	0.10	0.70	0.20	0.30	1.90	56	180	20	54	52
F	0.10	0.60	0.30	0.30	1.90	56	155	30	54	52
15	0.10	0.90	0.0	0.20	1.60	56	232	0	48	26
16	0.10	0.80	0.10	0.20	1.60	56	206	10	48	26
17	0.10	0.70	0.20	0.20	1.60	56	180	20	48	26
18	0.10	0.60	0.30	0.20	1.60	56	155	30	48	26

For the purpose of our study, these glazes may be conveniently divided into three groups and the relations of composition (in terms of empirical formulae) of the members of the groups shown graphically by the use of parallelograms, as in Figure 1. Of course in this method of representation there is necessarily some duplication.

Trans. Am. Cer. Soc. Vol. XV Fig. 1 Staley



Securing the Trials. The glazes were applied to soft-burned, white, wall tile and fired at cones 09, 02, 4, 8 and 10. The burns at the lower cones were made at the University, but the trials for cones 8 and 10 were fired in commercial kilns.

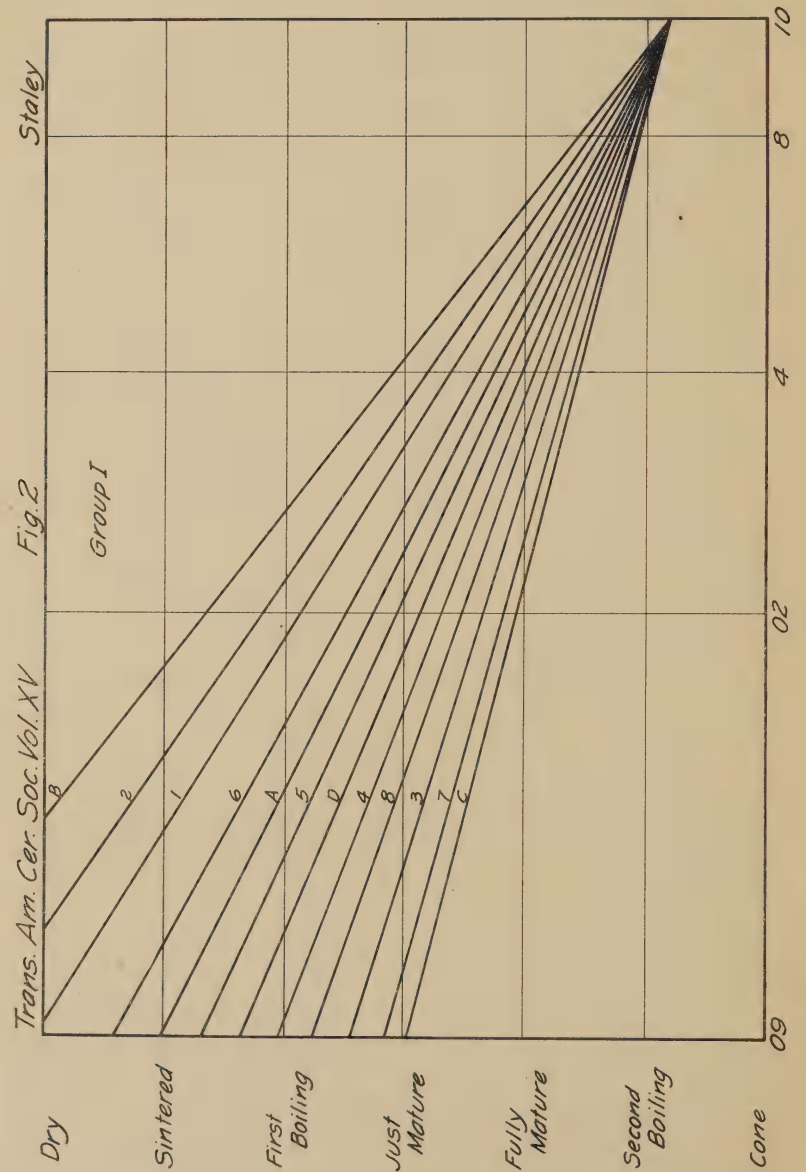
General Results of the Burns. The results of the burns consisted of a lot of bright raw lead glazes at various degrees of maturity. The fact that every glaze, which matured at all, came bright is ample justification for the general faith in the oxygen ratio of 1 : 2 for bright raw lead glazes.

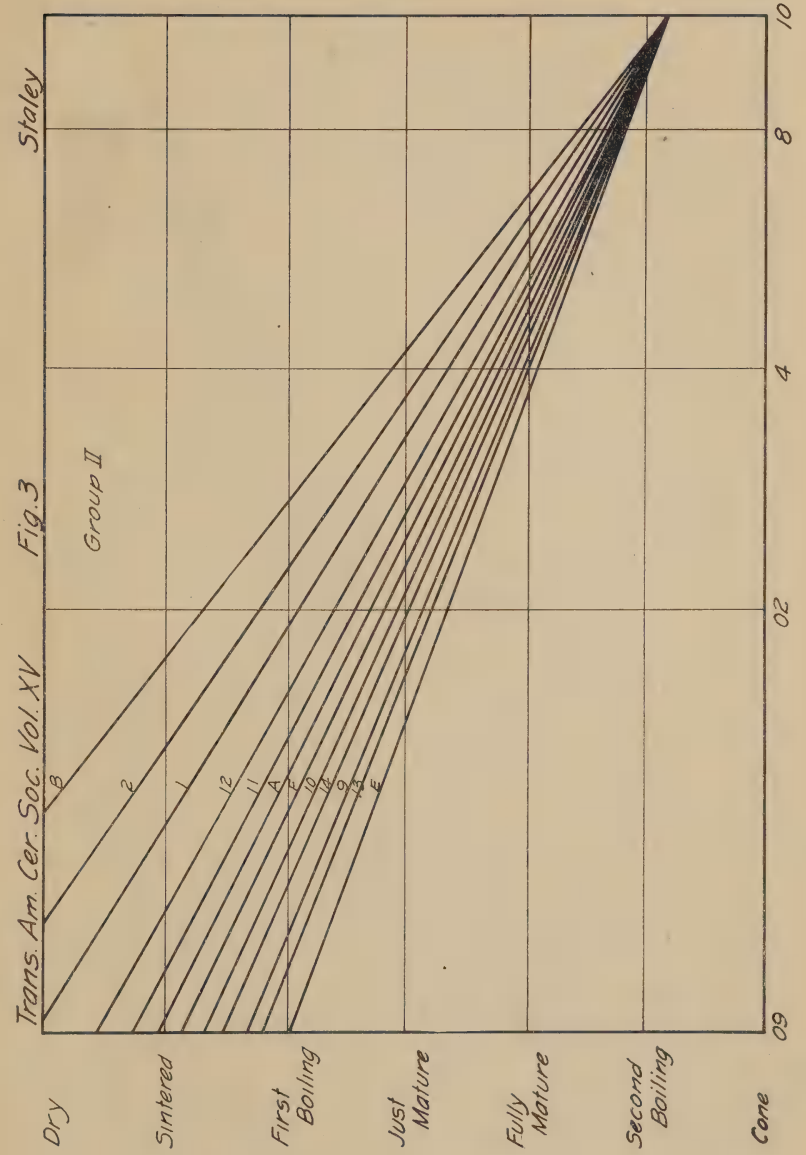
Study of Heat Range. The trials representing the glazes in each of the three groups were arranged in the order of length of heat range. The "life history" of the various glazes was then plotted as shown in Figures 2, 3 and 4. In general we can say that the glazes varied widely in fusibility at the lower cones, but those which were more refractory at the low cones developed at a more rapid rate, so that at the highest cones there was little difference in all the glazes. This of course means that *the more fusible glazes had the longest heat ranges.*

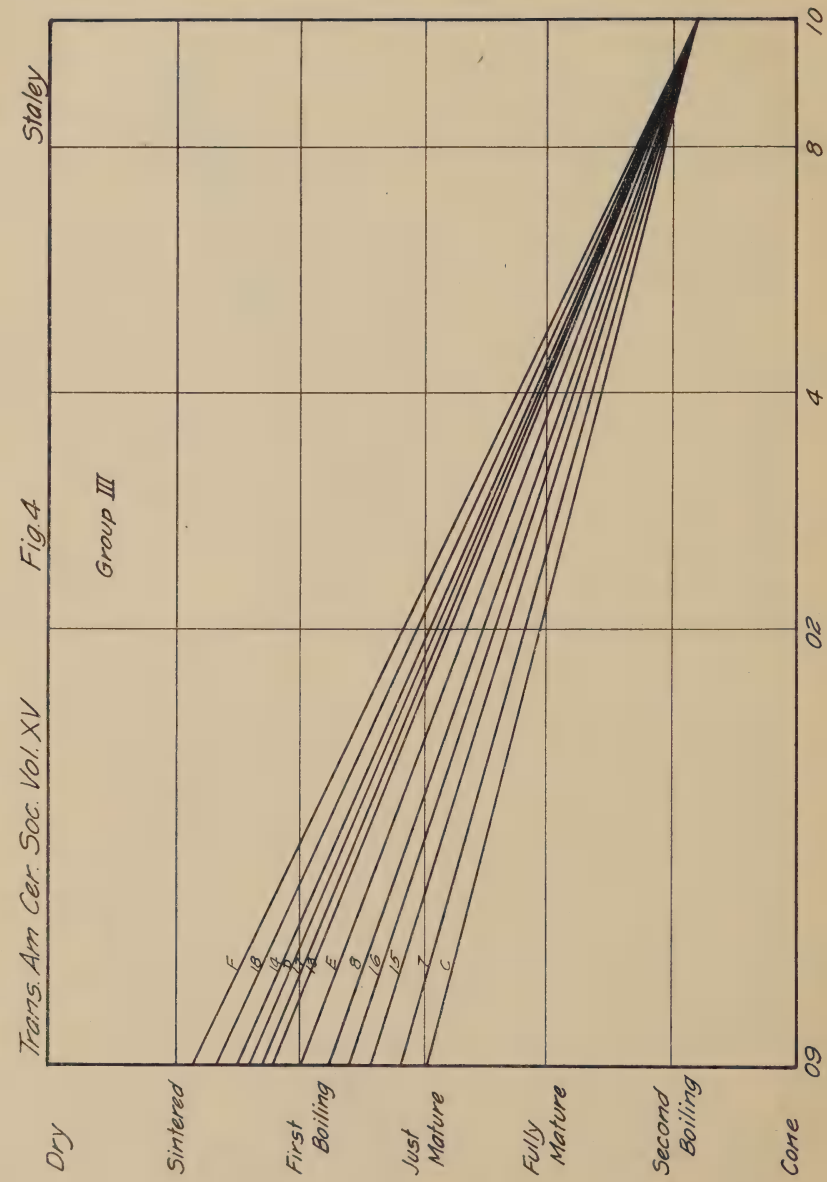
For an explanation of the peculiar arrangement assumed by the "life history" lines of the glazes, it is necessary to refer to physical chemistry considerations. At the temperatures of our kilns, glazes are liquids, just as water, alcohol, oils, etc., are liquids at ordinary temperatures. It has been demonstrated within the last few years that molten magmas are subject to the laws of viscosity that ordinary liquids obey,[1] and, therefore, we should expect these liquid glazes to follow the same laws. Since the maturing of a bright glaze consists primarily of the development of progressive degrees of fluidity in the molten glaze, the viscosity-temperature lines of the molten glazes will practicaly constitute the "life history" lines of the glazes.

The viscosity-temperature line of any liquid, including molten magmas, takes the form of a parabola; in other words, the viscosity at first rapidly and then more gradually approaches a minimum value. Probably due in large part to the parabolic character of the individual curves, it has been found that where the viscosity-

[1] Jahrb. f. Mineral; 1908, II, p. 152; Electrochemie, XII, p. 578; Monatschefte, XXXII, p. 643; Am. d. Physik., XXI, 287; Eighth International Congress of Applied Chemistry, V, p. 127.


Trans. Am. Cer. Soc. Vol. XV
Fig. 2
Staley
Group I
B
2
1
6
A
5
D
4
8
3
7
C
Dry
Sintered
First Boiling
Just Mature
Fully Mature
Second Boiling
Cone
09
02
4
8
10


Trans. Am. Cer. Soc. Vol. XV
Fig. 3
Staley
Group II
Dry
Sintered
First Boiling
Just Mature
Fully Mature
Second Boiling
Cone
09
02
4
8
10
8
2
1
12
11
A
10
9
E


Trans Am Cer. Soc. Vol. XV
Fig 4
Staley
Group III
Dry
Sintered
First Boiling
Just Mature
Fully Mature
Second Boiling
Come
09
02
4
8
10
F
13
14
12
E
8
16
15
7
C

temperature lines of a series of liquids of the same general type are plotted, the curves may diverge widely at low temperatures but they tend to coincide at higher temperatures. A well known illustration of this behavior is found in lubricating oils for use at relatively high temperatures. A series of such oils will vary immensely in viscosity if tested at atmospheric temperatures; but if the viscosity is measured at the temperature at which they are actually used, little difference will be found. The plot of the viscosity-temperature lines will consist of a fan-like arrangement of parabolic lines. The writer has found the same relation to hold in plotting viscosity-temperature lines of molten borate glasses.[2]

The only thing lacking to bring the action of our series of glazes under the general laws of viscosity for a series of liquids is to explain the absence of parabolic form in the lines as plotted. In brief, we have arbitrarily made the six stages in the development of the glazes of equal width. If we are willing to grant the almost obvious truth of the assumption that, as far as viscosity is concerned, there is a wider gap between a rigid dry glaze and a sintered glaze or a sintered glaze and one in the first boiling stage than there is between a glaze that is just mature and one that is fully mature or between a fully mature and a glaze in the second boiling state, we see that the lines representing the development of the various glazes should have been parabolic in form.

Study of Crazing. Having the samples we made a brief study of crazing. The results are tabulated in Table II. It will be seen that the glazes with long heat range were also free from crazing over the widest range of temperature. The chief reason for this is that these glazes were fully mature over a wider range of temperatures than those with shorter heat range. The fact that immature glazes are prone to craze is well known. Thus, the width of the temperature range over which a glaze will be free from crazing is also largely controlled by viscosity-temperature relations. Another possible reason is that these glazes contained the highest percentages of lead oxide, which substance seems to have a beneficial effect on the general working properties of glazes, as will be

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[2] "The Viscosity of Molten Glasses," Eighth International Congress of Applied Chemistry, Vol. V, p. 127.

testified by those who have attempted to make leadless glazes for use at low temperatures.

Relation of Theory to Practice. Factory practice in many branches of ceramics, including the making of glossy glazes, has

TABLE II

GLAZE	CONE[1]		
	02	4	8
A	Immature	Crazed	Crazed
1	Immature	Good	Crazed
2	Immature	Crazed	Crazed
B	Immature	Immature	Crazed
3	Good	Crazed	Crazed
4	Good	Crazed	Crazed
5	Good	Good	Crazed
6	Immature	Good	Crazed
C	Good	Good	Good
7	Good	Good	Good
8	Good	Good	Good
D	Crazed	Good	Good
9	Crazed	Crazed	Good
10	Immature	Good	Good
11	Immature	Good	Good
12	Immature	Crazed	Good
E	Crazed	Good	Good
13	Crazed	Good	Good
14	Crazed	Good	Good
F	Immature	Good	Good
15	Good	Good	Good
16	Good	Good	Good
17	Good	Good	Good
18	Immature	Good	Good

[1] No glazes free from crazing were found in the cone 09 burn. The glazes for the cone 10 burn are not included as they were all overburned. None were crazed.

been well developed for centuries. The only function the modern ceramist can perform is to search out and formulate the laws to which this empirical practice has, often unwittingly, conformed.

As has been the case in the development of all sciences, we are finding in ceramics that the rules of the art are dependent on the laws of the fundamental sciences, physics, chemistry and mathematics.

In this particular instance, we find that the laws, well known to physics, for viscosity of liquids have been an unseen but potent force in determining factory practice in the making of glossy glazes. These laws have made it necessary for the man who wanted a glaze that would be workable over a wide heat range to choose a fusible composition. These same laws have made it possible for the man who wished to mature his glaze at a relatively high temperature to use a composition less rich in low temperature fluxes, but have also determined that he would have to keep accurate control of his temperatures and that he would have a glaze liable to craze. Factory practice has simply been forced to obey the laws of physics.

CONCLUSIONS

1. Molten glazes obey the well-known laws of viscosity for liquids.

2. As results of 1, the more fusible glazes in a series of similar compositions have the longer heat ranges and are free from crazing over the widest ranges of temperature.

3. Factory practice in the making of glazes has been forced to obey the laws of physics in an empirical manner.

DISCUSSION

Mr. Purdy: Mr. President, the facts cited by Professor Staley are quite true, that the more fusible the glaze, the longer the heat range. Glaze C would become a very short range glaze, unless applied thick, as I think some of those here know, because it would take up so much body and the material offered by the body would be so irregular in composition and distribution, that you would get an unhomogenous mass that would blister and buckle up, and if you got it through as you describe, you would have a very unusual accident.

Prof. Staley: This glaze did eat into the body somewhat at the higher cones. I was not saying that it was a commercial glaze, but

I wish to state that I did not get any such blistered mass as Mr. Purdy describes. It came to a nice, glossy glaze the whole way through, and those glazes were burned on a soft burned body, therefore they had an excellent opportunity to eat into the body.

Mr. Watts: I would like to say, in this connection, that throughout southern Europe and in Switzerland they are making now, and have made for the last hundred years or so, glazes, which they use on their soft domestic clay bodies for dishes and general pottery, that figure out some place between C and 8 in Group I. Those glazes mature over an enormous range because the kilns are very crude. The kilns consist of a firing chamber like an ordinary fire box under a boiler with a more or less crude muffle above. In the top of the muffle often it is quite hot while in other parts it is at hardly more than red heat. They fire their material all in that crude way; and while the glaze varies in appearance, I could not see, in looking over quite large quantities of their ware, where there was any great percentage of it which was in any way unmarketable. To roughly estimate the temperatures I should say that it varied from about cone 010 or perhaps 08 to about cone 2 or 3. That is simply a rough judgment, but I am satisfied that it reaches or approaches that range.

Mr. Purdy: I have a better story than that. In our business, we used a glaze having one PbO, a dandy glaze, quite universally adapted to most anything you wanted to put it on, red tile or as a saggar wash. If we ran out of glaze any other place, we would put a little of that in, so that beats your story. But as a general proposition this glaze, C, is is a very treacherous one.

Mr. Watts: Concede that it is a treacherous glaze; at the same time I cannot see but what Prof. Staley's statement is true that, so far as his observation goes, it has done what he says it would do, that is, it has matured and remained practically matured, not materially deteriorated, over that very large range. I think you would find that a great many glazes in any series, wouldbe treacherous glazes; in fact, there are very few that are not treacherous.

Mr. Purdy: You understand, do you not, that I agreed with Prof. Staley in his general premises that the more fusible the glaze, the longer the heat range? My own published articles on glazes sustain this statement.

Mr. Watts: But you said when you didn't put it on a body.

Mr. Purdy: When you put it on a body, you have to make exception in the case of the softer lead glazes. There's no question at all but what that formula C can be put through a great many kilns a great many times and come out perfect; but for general application, that would not be a glaze of commercial possibility. So if you want a glaze with a good heat range, you've got to stay away from those which have been made very soft by high lead or apply them as a thick coating.

Prof. Staley: I want to call your attention to the fact that I was not trying to make glazes. I was trying to develop the physical principals that control the length of heat range in glazes. I am perfectly willing to grant that in any series of glazes the one with the very longest heat range might not be the very best to use when all other factors are taken into consideration.

Mr. Ortman: On the general subject of relation between fusibility and heat range of glazes, I simply wish to add an observation made a number of times on glazes of a wholly different type. I refer to glazes of the Bristol type maturing at cone 7 to 8. The results of a number of series, made up of glazes of varying fusibility both in mat and glossy finishes, have always checked, in general, Prof. Staley's conclusions, viz: that the more fusible the glaze, the longer the heat range.

THE REQUIREMENTS OF GLASS FOR BOTTLING PURPOSES

BY R. L. FRINK, LANCASTER, OHIO

The question of the requirements of glass for bottles has become a serious question, and one which the bottle manufacturers, and more particularly the bottle users, are beginning to consider very seriously, particularly those who bottle carbonated beverages where the bottle not only has to withstand the corrosive action of the liquids placed in them, but also a fairly high pressure, and must also withstand quite severe changes of temperature due to the washing and steaming process which they undergo in cleaning. Therefore, we have a severe condition imposed upon the bottles.

In this series of analyses or investigations, I have found most surprising variations in composition of the glasses of which bottles are made, not only in the product of different companies but considerable variation in the composition of bottles made of glass from the same furnaces, or factories operated by same concerns and supposedly under uniform conditions.

Bottles are usually manufactured in tanks of rather small capacity as compared with window glass tanks. The furnaces do not run, as a usual thing, more than 135 tons capacity; and as a consequence there is a condition set up which permits of a frequent change in composition. The bottle manufacturer usually is not very conversant with chemistry or with the conditions which will alter the composition of the glass, therefore, he purchases materials which are not manufactured under known and definite conditions, and consequently are unknown to him so far as exact composition is concerned. If he can not get limestone from one quarry he obtains it from another. His formula may call for burned lime, and if so the amount of lime specified always presupposes that the lime is a calcium oxide and 100 percent pure. If it should happen to call for calcium carbonate, or crushed limestone, it likewise is presumed that the stone is a pure limestone. As will be seen later, these are far from being the true conditions of affairs.

In making this investigation, I have endeavored to obtain information which would be useful in determining the adaptability

of the various glasses as found on the market for the purpose of bottling beer and carbonated beverages, either alcoholic or non-alcoholic. The method pursued was as follows: The bottles were purchased filled with the beverage and an endeavor made to determine the length of time which had elapsed since it had been placed in the bottle, the condition of the beverage as to its alkalinity, as to the probability of any deterioration having been produced by the solution of the glass, and as to any noticeable defect of the beverage upon the glass was noted. While such investigations were made with great care and caution, there was but very little accurate and positive knowledge obtainable, due to my inability to obtain specimens of the beverage manufactured at the same time which had not been retained in glass vessels. However, several instances were noted in which beer made and bottled at the same time in bottles of different manufacture, or of different composition, showed conclusively that the soluble constituents of glass have a very harmful and deteriorating effect upon beer or saccharinous liquids. By comparing the effects noted in the case of the highly soluble glass as related to a highly insoluble glass vessel, I considered it reasonable to assume that the marked deterioration and decomposition found in several instances are attributable to the high solubility of the glass of which the bottle was composed.

One particular instance worthy of special mention was a bottle of grape juice. This was a pint bottle of white glass containing a well-known brand of grape juice, which contained a considerable quantity of reddish black precipitate, and the juice had got fairly under way towards formation of considerable acetic acid. Another bottle which came in the same shipment from the factory, although of course there is no knowing that it was made at the same time, contained substantially no precipitate and seemed to be in perfect condition. In the first instance, it was found that the solubility of the glass was 10.11 milligrams while in the second instance it was a little less than 2, the test being made as described later.

In the case of beer, several bottles were taken, some being amber and some being green glass, and it was found that in nearly every instance the green glass is more soluble than the amber glass. It has occurred to me that here lies an explanation for the prefer-

ence of manufacturers for the amber glass bottles over the green bottles as being better adapted to the bottling of beer and to maintaining its quality, also that the lower solubility of the amber glass has more to do with the maintaining of the quality of beer than has perhaps the exclusion of sunlight, which is usually given as the reason for this preference.

From this case of beer, there were found to be two bottles one of which showed considerably more deterioration than did the other, and this one showed by subsequent analysis that it contained less than 3 percent of lime and in excess of 26 percent soda, showing a solubility of nearly 14 milligrams per 100 cc.

Table 1 shows the composition and solubility of a number of bottles investigated.

TABLE I

NO.	CaO	Na_2O	MgO	Al_2O_3	SiO_2	SOL. MG.	CC.	WEIGHT	COLOR
3721	8.74	13.41	2.03	3.09	72.73	4.1	233	315	Amber
3722	8.56	19.91	1.25	1.86	68.42	7.3	230	310	Green
3723	10.23	15.31	3.82	7.95	62.69	3.8	238	445	Dark green
3724	12.46	8.66	0.93	1.84	76.11	2.8	230	380	Green
3725	10.04	16.41	0.90	2.33	70.32	9.2	233	385	Amber
3726	11.60	13.91	0.62	2.53	71.34	1.1	230	400	Green
3727	9.65	16.41	1.01	5.71	67.22	10.11	239	440	Amber
3728	8.17	17.31	0.91	1.89	71.72	8.57	235	340	White
3729	9.65	17.03	0.74	2.01	70.57	9.2	233	340	Green
3730	9.65	16.88	0.81	1.63	71.03	9.0	235	...	Green
3731	5.95	20.04	1.38	1.61	71.02	13.2	238	...	Amber
3732	4.60	18.07	4.00	3.27	70.06	8.8	228	631	Green

The column headed "Sol. mg." is the amount of milligrams dissolved in 100 cc.
"cc." indicates capacity of bottle.
"Weight" indicates the weight of the empty bottle.

These tests were conducted as follows: The bottles were washed with 20 cc. of hydrofluoric acid (HF) and 25 cc of water until the acid was completely spent, which removed the inner coating or surface of the bottles in order that the case-hardened surface, or chill effect on the interior, would be removed and a uniform surface condition be presented to the solvent action of the water, as it has been found that the surface of glass always has a coating or chilled skin, which is of unequal resistance to the solvent action of liquids. After the acid was spent, it was washed out, and the bottles rinsed

with neutral water until no acid reaction could be detected, after which the bottle was filled with boiled neutral distilled water, and was maintained at a temperature of from 70 to 80°C. for a period of 48 hours. Determination of the alkali was then made, and the amount of soluble matter determined by evaporating 100 cc. of the solution to dryness in a platinum dish.

I find that the lime varies greatly in the different specimens of bottles analyzed, and is present in amounts ranging from 3.3 percent to as high as 12.46 percent. It is obvious that such a great variation in lime is not only uncalled for but impracticable. Perhaps here is an opportune moment for pointing out the cause for this great variation. I have found numerous instances wherein the glassmaker was working under the presumption that he was obtaining 8 percent of lime or calcium oxide in his glass, his formula calling for an amount of lime which, if the raw materials were of a purity and quality or composition called for by the formula, would produce a glass that would contain substantially 8 percent calcium oxide, or a rational formula of $2\frac{1}{2}$ SiO_2 to 1 of lime and $2\frac{1}{2}$ SiO_2 to 1 soda.

However, the facts as found were in most cases departing to a great degree from the specifications given in the formula and the presumptions of the manufacturer, for he usually would purchase lime supposed to be burned lime or calcium oxide, but this would vary in the quantity of magnesia so that the magnesia content would range from 6 percent to 37 percent. Moreover the amount of hydration and the degree of absorption of carbon dioxide and dioxide and water was found to have taken place to a variable extent according to the conditions under which the lime had been stored, the length of time which has elapsed between the making of the same and the using, and other factors which increased or diminished the amount of gases or moisture which has been absorbed by the line in the powdered form, to which it was usually reduced and which form it is usually demanded by the glassmaker.

This also accounts for many of the difficulties and much of the poor glass with which the glass maker has to contend when he is not possessed of knowledge which he should have and which he would be able to secure through the services of a chemist, or which

he might be able to easily obtain by the use of simple methods and apparatus with which he could equip himself. One might readily assume that either glassmaking is a process susceptible and permissible of an enormous degree of variability in its operation without injury to the product, and therefore a business void of technique and a process entirely lacking in fixed and definite relative proportions or relation, or else on the other hand, the product manufactured and turned out under such conditions must obviously be lacking in certain requisite properties demanded by the consumer. One might almost assume in the light of such conditions that the glassmaker could without serious inconvenience or difficulty easily dispense with such expensive apparatus as scales, and particularly those expensive ones known as "secret" or fixed weight beam scales, for on an average he could approximate the quantity of at least the lime, and obtain as accurate an amount of calcium oxide, should he be using pure calcium oxide, as he is now able to do with the aid of the expensive scales and the uncertain and unreliable lime product that is usually employed in the making of bottles.

Yet the superintendent and the workman are very careful and particular to weigh out their raw materials with nicety and painstaking in order that the proper amounts shall be incorporated in their batch mixture. Few of these men realize as yet that these raw materials vary in themselves to such a degree, and that they actually contain in some instances less than 40 percent of the chemical compound which they are supposed to contain. It is fortunate that the lime is substantially the only ingredient which is susceptible to such wide variation, or otherwise it would be difficult to imagine what the result might be and what difficulties might develop.

In all instances where I have found these conditions to prevail, I have most earnestly advocated changing the batch formulas and substituting the required amount of ground raw limestone for burned lime which many of them now call for, and which the glassmaker now demands. By so doing they are able to secure substantially uniform conditions and results insofar as the melting, annealing and color are concerned, for it is rarely, if ever, that one finds variations in the purity of raw limestone which alters the available amount of calcium oxide by more than 2 percent, which would produce a variation in the quantity of calcium oxide in the

finished glass of ½ percent or less, instead of 6 to 8 percent, as is now possible and many times occurs.

While it is true that in using ground limestone the melting conditions are changed somewhat, causing a greater foaming and more extended melting area; yet at the same time it will be found that after the conditions have once been properly produced and understood, and the control of the furnace to meet these conditions has been worked out so that they can be definitely handled, the making of a good glass maintaining uniform color and securing maximum production will be greatly simplified, and all factors entering therein will be better understood, and more easily controlled. This change once made, the glassmaker will never again return to the use of burned lime as now found in the market. It must be admited however, that could burned lime of definite composition be obtained, it has certain advantages over raw limestone; but my experience of over twenty years in the investigation of raw materials proves to me that it is the most unreliable constituent in glass and in my opinion is responsible for 75 percent at least of the difficulties in maintaining glass free from cords, stones, blisters, and is very potent in causing breakage, loss of color, poor working metal, etc.

I think it is safe to say that the major portion of the breakage occurring in the washing and steaming of beer or beverage bottles, and without doubt a considerable of that occurring in charging and filling of these bottles, can be attributed to laminations and consequent strains set up by the heterogeneous mixture of glasses caused by the rapid changes in the amount of lime introduced in the batch. Too much emphasis can not be laid in this point, for if the glassmaker wishes to make a bottle which will withstand the conditions imposed upon it by the various methods employed in the bottling of beverages, and of cleaning such bottles, he must recognize the fact that his glass must be free from laminations and strain, a condition which must inevitably occur where burned lime of a character now offered upon the market is used.

I have not mentioned another prolific source of trouble, although of a lesser character, but which too is found in the lime, and will not here attempt to enumerate the many detrimental properties, for some of these are as yet mooted questions, not having been sufficiently studied for us to have at hand positive knowledge

concerning their effects. Here I refer to magnesia. I will say, however, that there is one large producer of lime in Ohio, who furnishes lime to a large number of manufacturers all over the country, which has gained a wide reputation, but which I consider to be greatly inferior to that of many of the lesser known and smaller producers, and whose product has been the cause of producing all of the herein mentioned difficulties and conditions insofar as lime or its contamination can produce it. I have found this lime when sold as burned lime to contain as high as 45 percent of calcium carbonate, and as high as 40 percent of magnesia. While these quantities are not detrimental to the making of a good glass when occurring definitely and constantly in these proportions, they are exceeidngly injurious, and cause endless trouble as herein set forth. I have known the amount of calcium oxide to vary in two cars of lime received at the same time, presumably coming from the same quarry, approximately as follows: In the one car the calcium oxide found was 40 percent, magnesia 30 percent, calcium carbonate 25 percent, while in the other car calcium oxide found was 70 percent, magnesia 18 percent, calcium carbonate 6 percent. In both instances the balance to make up the 100 percent consisted of silica, alumina, sulphur and water.

It is not difficult to understand that trouble must ensue when the lime from the first car was all consumed and that from the second car was used. The glass made by using the same quantity of lime from the second car would inevitably demand more heat, would be less fluid, and would when coming down the tank and mixing with the glass containing the lime from the first car, prorduce great quantities of heavy cords, no doubt accompanied by numerous blisters, seeds and quite likely stones, and before and after these cords existed to a degree as to become noticeable, there would be profuse lamination with a consequent breakage in the factory, on the leer, in the warehouse, in transit, on the washrack, in the bottling machine, and all along the line.

The soda content of these glasses was found to run from 13.47 percent to as high as 26 percent, although this one analysis does not appear in the table and I have one bottle which showed even higher than this, it being slightly in excess of 28 percent.

The alumina was found to exist in quantities from 0.9 percent

to in one instance, that of an imported dark green bottle, 7.95 percent.

The magnesia was also found to vary greatly, as is to be expected and exists in quantities from 0.47 percent to 4 percent.

The silica also varies to a considerable extent, and is found to be from 66 percent to 74 percent. I have as yet found none higher than 74 percent.

The table gives the analyses complete of one series of bottles investigated, and I regret that I have not at hand all of the analyses, however, these are typical and will be sufficient to show what great variation there is to be found in what is supposed to be a uniformly constant and definitely constitued product.

I would direct attention to how the soda may effect solubility, as is seen in the instance where the soda exists to the amount of 13.47 percent. In this was 4.1 milligrams dissolved. In the instance of No. 3722, where there was present 19.91 percent soda there was 7.3 milligrams dissolved, and in No. 3731, having 20.04 percent soda, there was 13.2 milligrams dissolved, while in No. 3725 with 16.41 percent soda there was 10.11 milligrams dissolved. With 31.91 percent soda and 11.6 percent calcium oxide in glass No. 3726, we had but 1.1 milligrams dissolved. By referring to the table it will be seen that this glass is nearly a normal glass.

The figures here given, as also other analyses not here shown, indicate that as the soda increases and the lime decreases with alumina remaining constant, or substantially so, the solubility increases; and that where the soda decreases and the lime increases, alumina remaining substantially constant, the solubility decreases. With soda increasing, lime remaining constant and alumina increasing, the solubility decreases somewhat, but apparently alumina does not offer as much resistance to solubility as does lime. However, no doubt this is true only to a certain point, say 4 percent alumina, and higher alumina would offer greater resistance to solubility than might be supposed from figures here given. However this is presumption largely based upon the result of experiments in determining the solubility of opal glasses and the well known insolubility of porcelain and certain glazes. With soda and lime around 12 percent, and alumina at from 5 to 6 percent, there appears to be a composition of least solubility; and, neglecting the

quantity and presence of alumina, this corresponds substantially to the composition of a normal glass.

From the data secured and the results observed with the last mentioned glass containing the rather high percentage of alumina, it appeared to be particularly adapted to the making of beer bottles and bottles used as containers for sparkling wines, selzers, charged mineral waters, or any purpose where high pressures are obtained. No doubt it is due to the fact that most of our imported green bottles for this purpose contain an amount of alumina ranging from 5 to 9 percent that these bottles are preferred by our bottling establishments handling these beverages, as also are they desirable as containers for acids, alkalies, alcoholic and neutral liquids. They are superior to our domestic bottles by reason of their ability to withstand pressure and the corrosive action of liquids placed in them and are free, or substantially so, from laminations and strain.

I have a number of lantern slides that will serve to give an idea of the structure of glass under some of the varying conditions mentioned. These however, are negatives and not positives of photomicrographs of etchings of window glass; and although the conditions are not identical with those found in bottles, they will be more or less illustrative of examples of the heterogeneous character of glass when made under the above conditions. However, the conditions of variation of raw material exist to a very much less degree than has been found in these investigations, and as shown by the analyses given above. I regret that I have no specimens of bottle glass to show you, for the conditions found therein would produce etchings and plates which would greatly augment those seen here, and enable one to more easily differentiate the effects produced by varying compositions. I have made etchings of bottle glass, and have found several instances in which the acid would completely perforate the glass and eat through it in a small area of from perhaps 4 to 6 mm. This indicates that this area was sufficiently high in soda and low in lime to make it freely soluble in HF. The corrosion would prevail to a greater or less extent entirely through the thickness of the glass, which would be from 6 to 8 mm., while the balance of the exposed surface would be attacked by the acid to a depth of only $\frac{1}{2}$ to $1\frac{1}{2}$ mm.

These specimens are prepared by cutting a piece of glass about

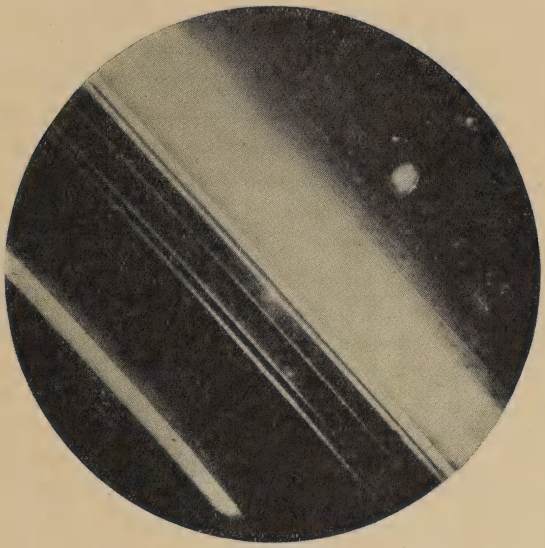


Plate 1

Plate 2

60 mm. in diameter, or sufficiently large to amply cover a platinum dish 40 mm. in diameter. The specimen is washed in water, dilute HCl, alcohol, ether, dried and placed in the dessicator for a period of fifteen or twenty minutes, after which it is weighed, the weighing being done for the purpose of comparing the loss or amount which the acid has dissolved. I always use 10 cc. of HF, which is placed in the platinum dish resting in a water bath kept at 90°C. This slowly evaporates the acid and gradually brings it into contact with the glass. After the acid has completely evaporated, the specimen is allowed to remain for a period of ten or fifteen minutes until perfectly dry, which after it is removed, washed off with hot water and 10 percent dilute HCl, dried by heating to about 100°C., again placed in the dessicator to cool, and again weighed. The specimen is now ready for observation under the microscope, by which means the photomicrographs here show are made, the magnifications being in most instances 80 diameters; but the plates showing strains and glass viewed in transverse section in polarized light are magnified 25 diameters.

The principal plates shown I will attempt to describe. The first (Plate 1) is a piece of glass in transverse section and is between crossed nicols. It will be seen to show ten or more stratums of glass having varying densities, and no doubt varying in composition. Certain ones of these end in the outer surface of the glass, which would make it extremely probable to cause rupture of the glass, should the same be subjected at this point to any marked increase or decrease in temperature, or should any strain be exerted upon this area which would tend to augment the character and degree of the strain existing within the glass. The method and means of determining the character of such strains was given in my paper presented to this Society in the year 1911.

The next plate (Plate 2) shows the effect of slow and protracted solution of materials foreign to the usual batch constituents, which in this instance no doubt was what would, at earlier stages of its existence, have been recognized as a stone, but which had existed in a melting temperature and within a magma of silicate compounds for a sufficient period of time to become substantially all dissolved. It can be seen that the glass formed thereby and in its immediate vicinity was considerable different in density, and had greatly

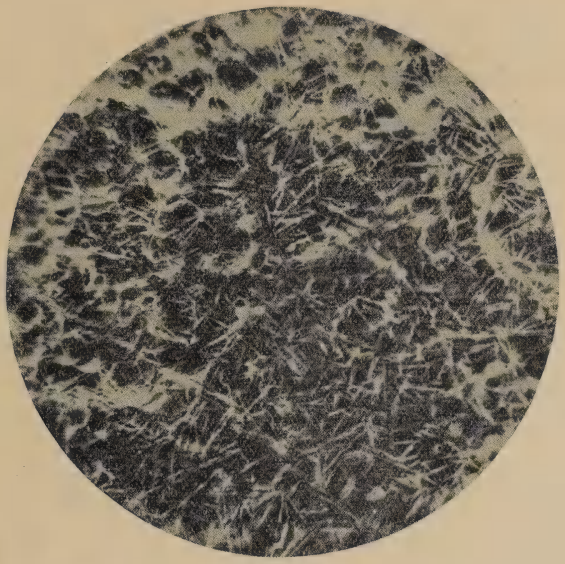


Plate 3

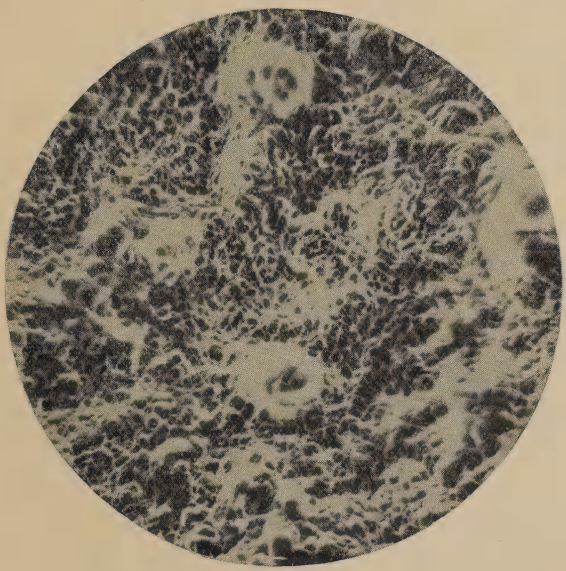


Plate 4

different optical properties from the glass more remotely surrounding it. Obviously by reason of its different physical properties, i.e., its coefficient of expansion and contraction, viscosity, specific heat and softening point, it was subjected to enormous strains, which were set up by the differential contraction and expansion existing in the preponderance o' glass surrounding 't.

Plate 3 shows a marked crystalline effect, which in th's instance is the beginning of devitrification. However, before etching, and to the unaided eye, this glass was perfectly clear, and one could discern no signs of crystals; but inasmuch as the crystals here remain, and are reposed in a magma of glass, and as it is well known that the higher lime silicates are less soluble in HF than the lower calcium compounds, it may be assumed that these crystals predominate in lime which has formed compounds whose refractive index so nearly approach that of the surrounding glass as to make them perfectly transparent and thereby conceal their presence.

Here I have a plate (Plate 4) which, in contradistinction to the one previously shown, is plainly indicative of the former existence of crystals; but it is seen that these crystals are no longer present, only the outlines remaining. As before stated, it would appear that here the surrounding glass in which they resided was of a composition which was higher in lime than were the crystals, and further from their crystallographic appearance and form it may be quite accurately deduced that these crystals are a silicate of soda and lime, containing a preponderance of silica.

I will also show several slides in which the principal characteristic feature lies in the size and regular or irregular disposition of the apparently cellular structure remaining after etching, in which the two extremes marked to some degree the hardness of the glass, and which it has been found corresponds quite closely with the amount of soda contained in the specimens. In Plate 5 the cellular structure is seen to be quite fine, regular and close, resembling kernels of wheat lying together, while in the other extreme, Plate 6, it will be seen that the structure is that which might be taken to represent a portion of a brain, and which I have given the term "brainy" appearance. These cells shown in Plates 5 and 6 if reduced to actual size would be 0.07 mm. and 0.18 mm. respectively in diameter. It has been found that as the soda increases

Plate 5

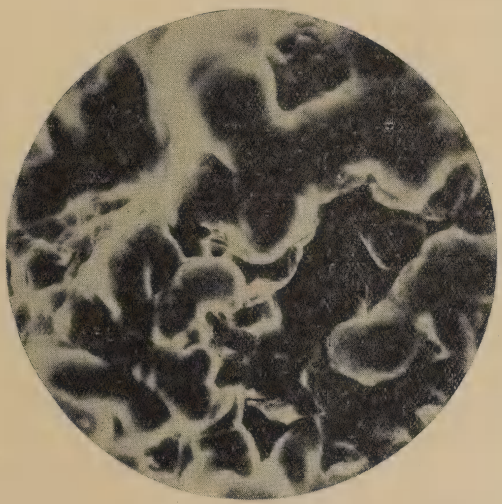


Plate 6

the size of the cell increases, or at least it is true within certain limits up to possibly 25 percent of soda when the maximum size of the cell would reach probably the neighborhood of 0.2 mm.

I might remark that this condition is of more than passing interest in view of the fact that when obseving this specimen under the microscope by the aid of subdued transmitted light, it will be found that the boundaries between cells assume a width of $\frac{1}{4}$ to $\frac{1}{2}$ mm., as here magnified, or actually 1.003 to 0.006 mm., and show a pronounced difference in color and in optical properties. However, it seems obvious that this does prove that glass is made up of cells or aggregates of minute masses either within an envelope or otherwise, each having its own definite composition. The etchings would seem to show and prove by the unequal degree of the attack of the acid that there is a considerable variation in this composition which it would seem would further furnish cause and explanation for the often very peculiar and erratic lines of fracture and manner in which glass breaks.

This would also seem to account for the next plate, Plate 7, which plainly reveals a definite area some 15 or 20 mm. wide, which completely traverses the specimen in one direction and wherein the acid has had very much less effect than upon the surrounding areas. While there was no disturbance of the glass in the making of this specimen, yet it will be seen that the cells are contracted and smaller throughout this narrow area than those composing the surrounding glass. This effect was produced by drawing a cold iron over the surface of the glass as it reposed in the pot just previous to a cylinder being drawn therefrom. The cylinder was made upon one of my window glass machines, which, briefly described, is a process whereby the glass is ladled by means of a metal ladle from the tank or melting furnace, is deposited in a shallow pot—and at this point the cold iron was drawn across the surface, but making little or no impression on the glass, producing only a chilled streak across the upper surface, perhaps one-half inch wide. After the depositing of the glass in the pot, a metallic bait, or ribbon, is lowered into the glass, which by its own heat attaches itself to the ribbon, after which this bait is drawn upwardly at a rate as to give the glass the proper thickness, which is governed by the rate of cooling as related to the speed of draw, or vice versa. Therefore it will

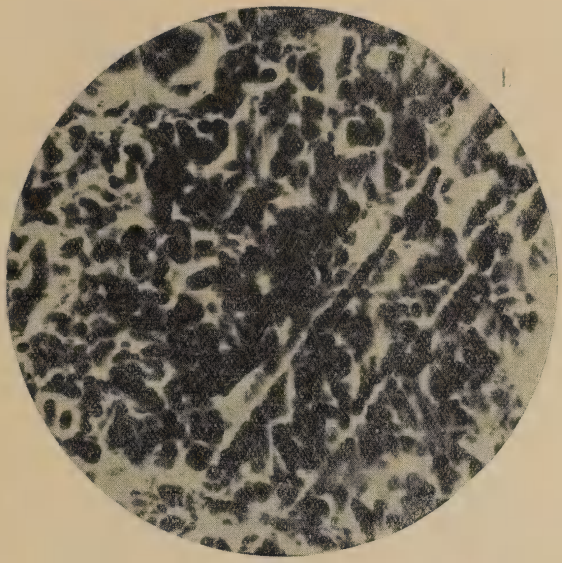


Plate 7

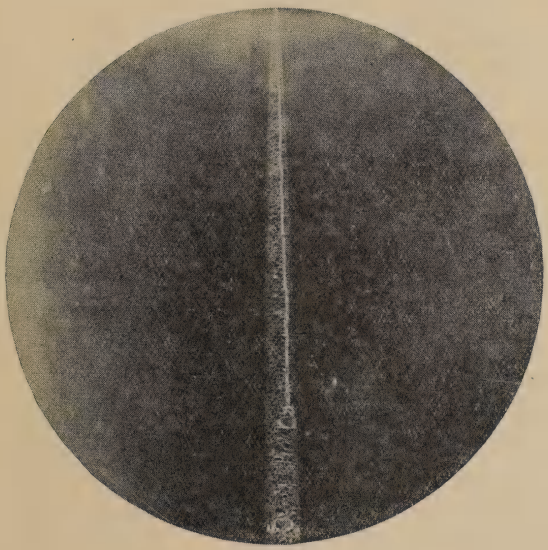


Plate 8

be seen that the glass rested substantially undisturbed in the pot, and as the cylinder was drawn this chilled portion was picked up and was drawn out until it had disposed itself throughout the mass of glass comprising the cylinder, and until all of the glass affected by the iron had entered into the construction of the cylinder. It is difficult to conceive what effect would have been produced by the chilling of the glass which would have altered its physical arrangement and its chemical properties to such an extent as to make it resist the action of the acid. It seems logical to assume that it may have brought about something analogous to a casehardening effect, which may have produced the formation of cells or aggregations which are protected by a higher fusing and more resistant lime silicates.

I have here another illustration, Plate 8, which shows portions of a blister that was opalescent in color. We at one time had considerable trouble with this condition, as there existed in the glass millions of these small blisters, whose dimensions were from 25 mm. long by 1 mm. wide down to microscopic dimensions. By high magnification and optical study, it was determined that these blisters were caused by condensation of arsenic. They were found to be partially filled with the octahedrons of arsenious oxide, and were caused by the use of arsenic in the batch and the filling in along with it of hot cullet, which incorporated the arsenical sublimates at a temperature below that at which the sublimate would form a sufficient tension to escape. Remaining in the glass until the temperature was reduced, the sublimate would condense, and the crystals here shown would form. The severe strain which surrounds each of these blisters was occasioned by the diminution in volume of the arsenical vapor, which produced an extremely high vacuum, and thereby caused a tension stress throughout this area.

In the next illustration, Plate 9, we see a condition which I believe to be an extremely rare one, and which is difficult to explain. It will be seen that there are radiating portions of the etched surface which has been substantially unaffected by the HF acid. These portions are about 2 mm. wide and 25 to 30 mm. long, there being four extensions from a central point, as the spokes of a wheel, irregularly situated. These, as is the surrounding glass, appear perfectly smooth and void of any cellular structural appearance,

indicating that this glass is truly amorphous. This condition prevailed throughout all of the etching as it was examined from time to time during the etching process, and the amount of etching acid used was, as I recollect, about 22 cc. or two and one-half times the usual amount, so that the amount of glass dissolved by the acid is probably 50 percent or more of the thickness of the glass. Further, analyses show that this glass was substantially what I term a normal glass, the residue from the etchings giving an analysis of 12.58 of lime, 13.85 of soda, 70.7 of silica, .42 of

Plate 9

magnesia and 3.25 of alumina. This specimen of glass I consider to be the only specimen of true glass that I have ever seen, for in all of its optical properties it indicates that it was perfectly homogeneous, and excepting for these radiating areas, it seems to be perfectly uniform and void of any lamination or cellular structure.

In speaking further of the requirements of glasses for bottles to meet all conditions, their composition should be as near as possible to that of what I term as a normal glass, that is, one containing from 13 to 14 percent of soda, about 12 percent of lime, 70 to 71 percent of silica, from 3 to 5 percent of alumina, with the magnesia

kept as low as possible, although in some instances it is advisable, or at least desirable, to allow the magnesia content to become as high as 2 or 3 percent to facilitate the fluidity or the working of the glass at the required speed demanded by semi-mechanical manufacturing conditions. This glass, if thoroughly melted and homogeneous, has a very high tensile strength, very low solubility, and, with fairly uniform annealing, will withstand the average conditions imposed upon it in the washing and steaming process and has ample strength to withstand the highest pressures in bottling.

In conclusion, we may summarize these conditions and requirements by saying that at the present time the manufacture of bottles in this country is carried on with no regard whatever for the physical properties, and in fact it is doubtful if our manufacturers realize that it is possible that their process of making the glass, or the ingredients contained therein, can affect the physical properties of the glasses constituting their product. When we can indiscriminately select specimens of bottles from several cases of beer, for instance, and find therein glasses varying in their constituents to the extent here indicated, it is obvious that either the manufacturer is ignorant of the physical and chemical attributes of these constituents, or that he has no regard or respect for the properties which these constituents give to the glass. However, I believe that the time is rapidly approaching when the brewer and the bottler of fruits and beverages, will take this matter up and will insist upon his bottle manufacturer supplying him with an article which will insure the permanency and quality of his goods.

These investigations are but preliminary ones, but I trust that they will be sufficiently pertinent to others that they will arouse interest in the minds of those who are in a position whereby they can follow them up and determine for themselves, and subsequently give to this Society their report, which I am sure will make very interesting reading when a greater number of conditions and more data and definite information is forthcoming.

DISCUSSION

Prof. Orton: How would the glass illustrated by the first slide look, supposing there were no strains there.

Mr. Frink: It would be perfectly clear, and there would be no

signs of any lines, or variations in the amount of light transmitted by the glass.

Prof. Orton: In the specimen showing the effect of the cold iron, is that a view of the sheet of glass on edge?

Mr. Frink: No, the specimen is lying flat.

Prof. Orton: In the specimen showing the blister, is the sheet on edge?

Mr. Frink: No, it is flat, and there were three plates made of this one blister as the high magnification required demanded three exposures to cover its entire length.

Prof. Orton: With the streak running through it.

Mr. Frink: Yes, sir. There was this broadened area in the center with these tail portions extending both ways, which are the minute crystals of arsenic.

Prof. Silverman: There is one point on variation of the composition of these glasses about which I should like to ask a question. I should like to know whether the variation is not due to the fact that bottle manufacturers are buying cullet all over the country because they can obtain it for little or nothing? This was brought to my attention particularly by the fact that you have one glass which is extraordinarily high in alumina. I know that in opal glass manufacture there is a great loss from breakage and I know that cullet is being sold at a ridiculously low price. I wonder if some of it landed in the plant where your bottles were made.

Mr. Frink: The bottle manufacturer has at last arrived at the very sensible conclusion that it does not pay to use opal cullet. In making an examination of a large batch of cullet which contained a thousand tons, I took over a ton of samples, mixed it up and crushed it and made several chemical analyses of it and found that the average was a very fair average of bottle glass; therefore I assume that it would not make much difference in the ultimate analysis and that most all the variation in glass of one concern is due to their raw material.

Prof. Silverman: I should like to ask Mr. Frink whether he noticed any difference when he etched glass which showed no strain in polarized light and glass which did exhibit the strains?

Mr. Frink: I meant to have spoken of that, particularly in referring to the one specimen where I called your attention to its

being the one with the cold iron. The strain in all directions was quite pronounced and can be found in the etched sample, although it is so irregular that it is hardly discernible unless you see the strain before etching.

Prof. Silverman: What I meant is whether samples which do not show the strain under polarized light will show crystals on etching?

Mr. Frink: Not necessarily crystals. You would not know there was any strain in the glass by looking at the etching, unless you could make the polarized light examination first, for instance, where you saw the specimen similar to grain in wood, and see the laminations running to the outside; in this case if you had made an etching on that outside surface at that point, you would by comparing the polarized light examination with the etching, find where the different lamina ended; and you would see pits, perhaps, indicating higher soda or might see a very close structure or "brainy" appearance.

Prof. Pence: I was very much interested in the slides which showed the crystal development. I would like to ask Mr. Frink whether there was any distinctive difference in compositions between the glass which showed the fine, needle-like crystals and the one which followed showing the blade-like crystals?

Mr. Frink: As a whole you mean, the glass as a whole?

Prof. Pence: Yes.

Mr. Frink: There is practically no difference, as a matter of fact all of those slides were made from glass made in the same tank and within three months of the same time, window glass of the composition I gave.

Prof. Pence: I asked this question because, so far as I can tell from my observation of the slide, the crystals were very similar in appearance to the crystals that I observed in mat glazes, and the fact that those crystals are shown to be present in the clear glass is a very interesting thing in a discussion on crystal structure and mat texture.

Mr. Doe: Do these show in polarized light?

Mr. Frink: Yes.

Mr. Doe: So they are all true crystals?

Mr. Frink: Yes, true crystals.

Prof. Pence: Were they very tiny?

Mr. Frink: They would vary in size, although the individual crystal will probably measure, I should presume, somewhere in the neighborhood of 150 or 200 microns.

Mr. Moore: All of the slides you showed us that had been etched, showed irregularity in the action of the hydrofluoric acid. Did you get any results in which the etching was uniform? Is it possible to get a glass so uniform in composition that the etching will be smooth?

Mr. Frink: You ask if it is possible. That, I could not say, but I have never yet seen one; the nearest we came to it was the last slide I showed where I said it seemed to be a marvelous structure. When we can get to the point where we can make one that will be smooth, I will be happy. That I consider to be the ideal glass.

REFRACTORY LININGS FOR ROTARY CEMENT KILNS

BY HAROLD A. HENRY, FENTON, MICHIGAN

The rapid growth of the cement business, and the evolution in burning which has resulted in the mammoth rotary kiln of today has left many unsolved problems. It cannot be expected that full and mature thought could be given to all the details, or that perfection can be expected or even aimed at in such a rapidly expanding industry. The fact that the mechanic rather than the chemist dominated the industry in its early stages has led to many wasteful and expensive designs and processes. The chief aim has been to get enormous output, and all other factors have been given only secondary consideration. This condition has left a great many problems which must be worked out by the cement manufacturer of today in an effort to cheapen his product.

One of the most important of these problems and one which has caused many failures and led to enormous expense has been the task of finding a cheap and durable lining for the rotary kiln. This lining must act as a protection to the iron shell of the kiln, as well as prevent to some extent the great loss of heat by conduction and radiation from the heated interior of the kiln. This heat loss by radiation from the shell of the kiln has been estimated from 20 percent to 35 percent of the entire amount of heat produced in the kiln.

There have been a great many different linings proposed and put into service. Among the most important of these are concrete, magnesite, bauxite, and fire clay brick. A concrete consisting of cement clinker, sand, and cement was used to quite an extent some years ago and, due to its cheapness and the similiarity of its composition to that of the cement material, gave fair satisfaction. The linings, however, required much repair, and necessarily a great deal of time was lost in operation of the kiln.

Magnesite brick have been used to some extent but have never come into general use. They are able to withstand the heat well, but are very expensive and, due to their dense nature, are not able to stand the sudden changes in temperature without cracking.

Fire clay brick and brick made from materials high in alumina

have been put on the market in great numbers for rotary kiln linings.

The rotary kiln lining question was still in its infancy when it became evident that no lining could be found which would be able to withstand the great heat and sudden changes of temperature, if this lining was not of such a nature that the cement material would adhere to it and form a protection. Thus the longest lived linings today are those which take up this coating the quickest and hold to it the best.

The brick which are used for these linings are 9 inches square on the outside and tapered on a 3 ft. to 5 ft. radius, depending on the size of the kiln; and when they are placed in the lining they form a tight ring about the inside of the shell.

There has been quite a question as to the desirable thickness of this lining, and formerly most of these brick were made from 9 in. to 12 in. thick. It has been found, however, by some companies that the cement coating will not adhere well to the brick until they have been melted down to a thickness of 2 in. to 4 in., thus giving easy radiating conditions and allowing the intense heat to be conducted from the face of the brick. For this reason many companies have substituted 6-in. brick and get equally good results. This theory would be borne out by the company which attempted to prevent radiation from their kilns by inserting an asbestos lining between the iron shell and the fire brick lining. The brick, however, under these conditions could not stand the heat at all and this attempt had to be given up. At present we must accept this great loss by radiation as a natural evil of the process, and be content to reduce it in other ways. A very porous, high grog, fire brick will give good results and has a tendency to reduce this radiation loss, as the open air passages form a good heat insulation. Because of this great loss by radiation, this process of burning cement has been called one of the most expensive and wasteful operations to be found in any modern industry.

The chief reason why a cement plant must be operated continuously is because of the great damage that is done to the lining when the kiln is allowed to become cold. When the brick becomes cold, the coating of cement material falls off and leaves the brick with no protection. Much of the inside face of the brick often falls off

with the coating. In some cases when the brick once loses this coating, the kiln must be relined before it can be started again.

The life of a fire brick lining in the hot zone of a rotary cement kiln is from three months to one year, provided the kiln is kept hot and in constant operation; but if for any reason the kiln is allowed to cool, this lining will not last nearly so long.

As the material which passes through the kiln is highly basic, we know from the first principles of chemistry that a brick of highly basic nature will be less easily acted upon by this high lime material than is an acid or high silica brick. So, all other things being equal, a brick high in clay substance and low in silica will withstand the action of cement material best.

The abrasive effect of the finely ground cement material is very slight so that in selecting brick for rotary kiln liners, it is not necessary to get hard dense brick as it is in industries where the abrasion is more severe. In fact the more porous brick give the best results both because of their highly refractory nature and because they are poor conductors of heat. Hard dense vitrified brick are also more apt to crack and spawl off on the face due to sudden changes of temperature than are the more porous brick. The porous brick can take up most of the expansion and change of volume within themselves and thus will not be effected nearly so much.

It is very important, however, that the brick shall be burned to such a temperature that all the contraction has been taken out of them, for if the brick contract materially after they have been placed in the kiln, they will become loose and fall from the lining. An effort should also be made to have the coefficient of expansion of the lining as near as possible to that of the iron shell. If the lining expands more that the shell, it is apt to crack and buckle in order to find an outlet for the extra volume. While in the other case, if the shell expands most the brick will become loose and the lining will be short lived.

It is not necessary however to use a high quality of brick throughout the entire length of the kiln, as the hot combustion zone in general is not over twenty five feet in length. This hot combustion zone should be kept as short and as near the front of the kiln as possible; but the size of the kiln, quality of fuel used, and efficiency

of the burner, all have a great influence on the length and position of this hot section.

A much lower grade of brick can be used in the cooler parts of the kiln, but an effort should be made to select brick which will transmit as little heat as possible. It is very important that the brick for this purpose should be hand moulded, and that the percentage of plastic clay in the brick be kept very low. The internal structure of a hand moulded brick has been proven to be much more symmetrical and tough, and for this reason it will hold together a great deal better than machine made brick.

In conclusion we find the most practical lining for rotary cement kilns to be hand moulded, high alumina fire brick of a porous nature and burned to a temperature of at least 2600° F.

DUST PRESSED BODIES

BY FORREST K. PENCE, COLUMBUS, OHIO

Introduction. The following paper is a report of an investigation that was conducted in the Ceramic Laboratories of the Ohio State University in which a study of the effect of variation in composition of dust pressed bodies was made in much the same way as has been done in the study of plastic bodies.

Composition. The bodies were compounded from white burning materials as follows:

Clay constituent..... { 3 parts North Carolina kaolin
2 parts domestic ball clay { 1 part Tennessee
1 part Kentucky

Feldspar constituent.....Normal potash feldspar
Flint.....Ground quartz sand

The various body compositions are shown by means of the triaxial diagram in Figure 1.

Preparation of the Bodies. 1. Batch weights determined from the triaxial diagram and figured to the basis of 1000 gms. batch for each body.

2. Bodies weighed and weight checked by weighing total batch.

3. Blunged by hand in one gallon jars.

4. Sieved through 150-mesh screen.

5. Slip concentrated on plaster protected by muslin and finally dried completely in dryer.

6. Crushed to $\frac{1}{4}$ inch size.

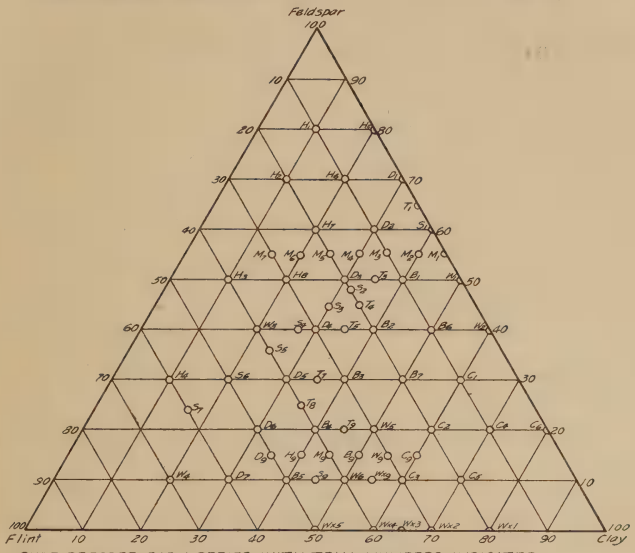
7. Tempered by careful addition of 10 percent of water by weight.

8. Ground in porcelain mortar to pass 20-mesh screen.

9. Allowed to stand over night in covered jar.

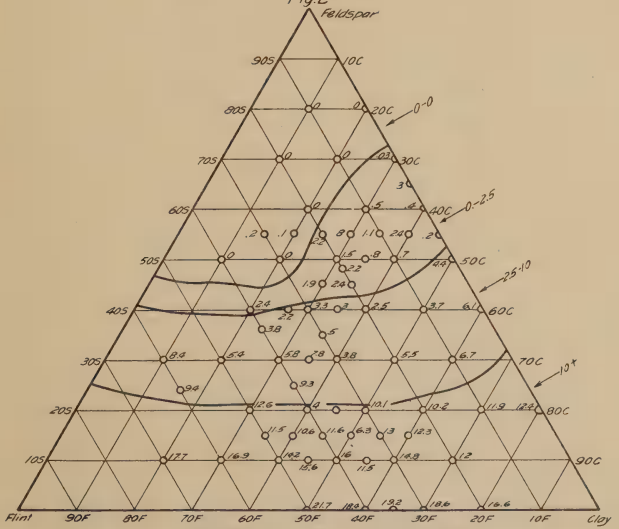
Making and Burning the Tile. The bodies were pressed into 11.3 cm. square tiles on a Crossly hand screw press. In order to obtain uniform pressing, all bodies were pressed by the same man, who was an experienced pressman. Three tiles were pressed from each body, and two of these were cut into three parts, making six small tiles and one large tile for each body composition to be divided

Trans. Am. Cer. Soc. Vol. XV Fig 1 Pence



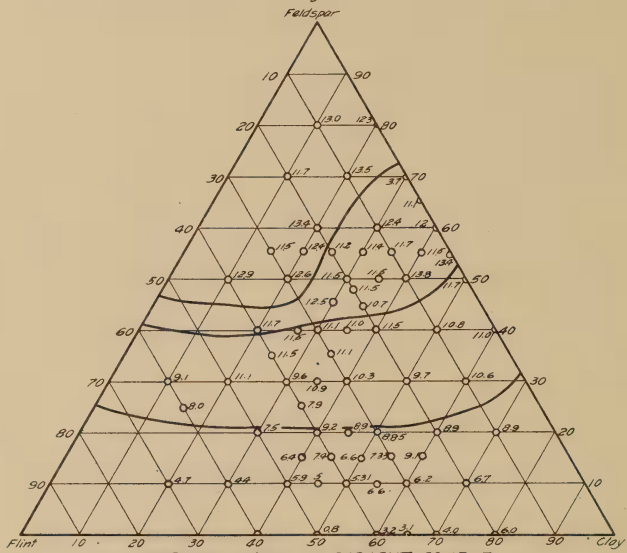
DUST PRESSED BODY SERIES WITH TRIAL NUMBERS INDICATED

Fig. 2



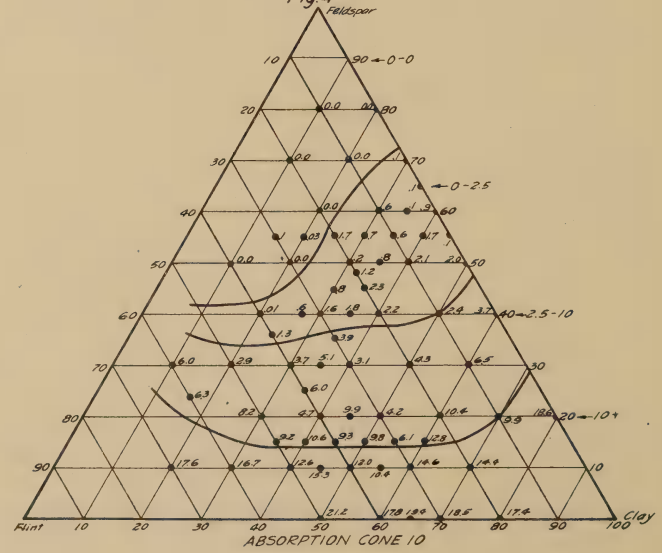
ABSORPTION AT CONE 7 IN PERCENT

Trans Am Cer Soc Vol. XV Fig 3 Pence



AVERAGE SHRINKAGE PERCENT CONE 7
AREAS AS DESCRIBED ON ABSORPTION DIAGRAM

Fig 4

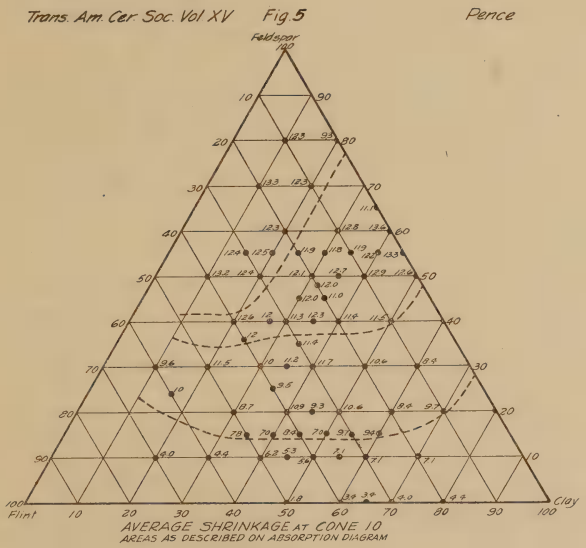


ABSORPTION CONE 10

between the two burns and distributed in different parts of the kiln.

Burning. Three tiles of each body composition were fired to cone 7. Four tiles of each were fired to cone 10. The time of firing was about 32 hours.

Vitrification. A study of the vitrification was made by the determination of average absorptions and shrinkages. The results are given in Figures 2, 3, 4 and 5.

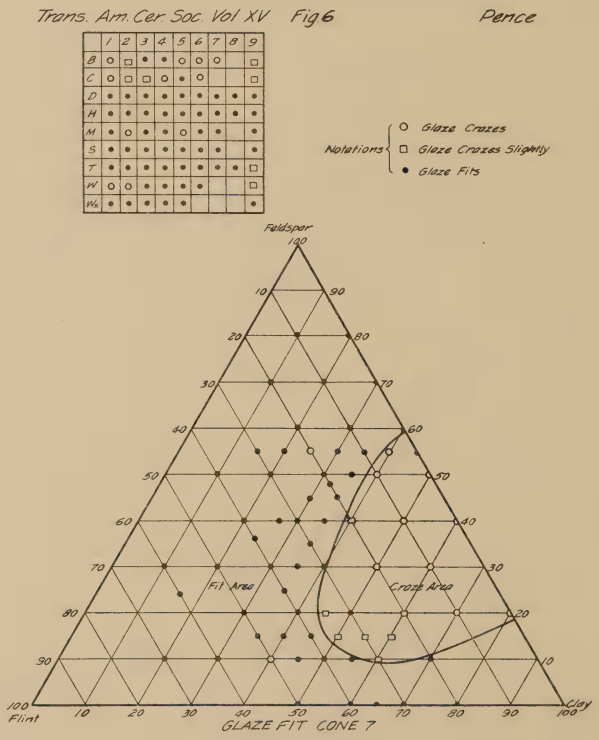


It is not deemed necessary to enter into a detailed discussion of the results as the charts speak for themselves. Perhaps the most interesting condition is found in the high feldspar portion of the diagram where the possibility of substituting flint for feldspar without materially altering vitrification is indicated. Bodies H_1 and H_2, however, by slight distortion, gave evidence of overfire. This area should be studied in greater detail.

In order to check the results, a number of body compositions were selected from various parts of the series and new batches weighed up and tiles made and fired to cone 10. In this case no body was constructed by the man who had made it before. The

check results are considered generally satisfactory within the limits of error.

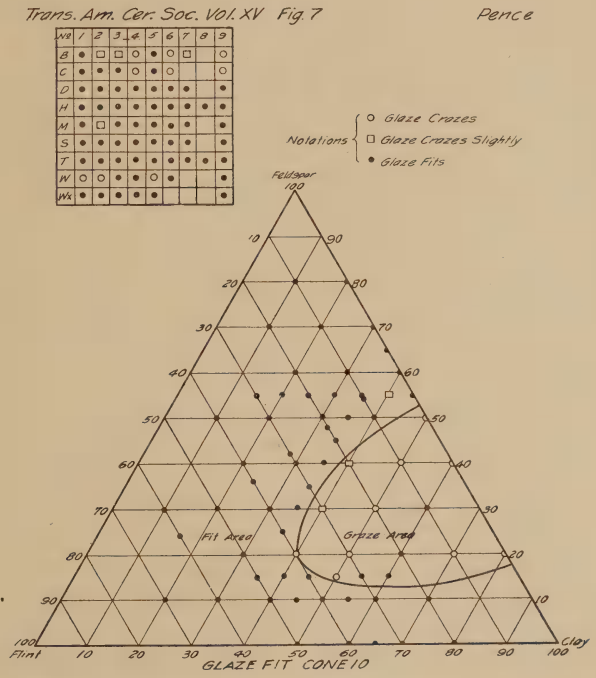
Glaze Fit. A study of glaze fit was made in which all the tiles were glazed with a standard white ware fritted glaze fired to cone 1. The results are shown in Figures 6 and 7. The results in general check those obtained in similar studies made on plastic bodies.



In connection with this study of dust pressed body compositions, a few trials were made to demonstrate the effect of the more important substitutions in materials and process of manufacture. The bodies in which such substitutions were made were fired in the same saggers with those of the regular series. The results are shown in Figure 8.

Conclusion. The results of this investigation are given with the purpose of affording a source of information concerning the general vitrification and glaze fit behavior of dust pressed bodies.

The wide range of composition available in such bodies has made it possible to extend the study over a much greater range of composition than would be logical in a study of plastic bodies.



Trans. Am. Cer. Soc. Vol. XV Fig. 8 Pence

COMPARATIVE DATA ON MISCELLANEOUS SUBSTITUTIONS

		Abs.		Shrink		Glaze	
		Cone 7	Cone 10	Cone 7	Cone 10	Cone 7	Cone 10
1	C_3	15.6	14.4	6.2	7.1	2 Glazes	Fits
	C_3 Prepared Plastic (B_8)	8.8	8.7	12.0	11.5	Fits	Few crazes
5	M_3	.85	.61	12.17	11.97	Fits	Fits
	Stone for Spar in M_3 (C_7)	2.1	1.58	11.5	11.5	Crazes	Fits
2	W_6		15.67		5.6		
	W_6 Prepared Plastic (C_8)	9.3	9.5	8.0	10.0	Fits	Fits
8	T_4	2.3	1.7	10.5	11.0	Fits	Fits
	Eng C.C. for Harris C.C. in T_4 (D_8)	.25	.12	12.39	11.94	Fits	Fits
3	B_3	3.6	2.9	10.5	11.7	Fits	Few Crazes
	B_3 Prepared Plastic (M_8)		.57		13.5		Fits
4	S_3	1.7	1.2	12.5	12.5	Fits	Fits
	S_3 Prepared Plastic (S_8)	00	00	12.0	12.0	Fits	Fits
6	T_4	2.3	1.7	10.5	11.0	Fits	Fits
	Stone for Spar in T_4 (W_4)	3.8	65	10.0	11.5	Fits	Fits
7	W_5	10.1	5.67	8.85	10.6	Craze	Craze
	(W_8) Stone for Spar in W_5	11.6	9.86	6.9	8.0	Fits	Fits
9	W_{x2}	18.57	18.68	4.0	4.0	Fits	Fits
	Eng C.C. for Harris C.C. in W_{x2} (W_{x6})	15.67	15.94	4.6	4.6	Fits	Fits
10	W_5	10.1	5.67	8.85	10.6	Craze	Craze
	(W_{x7}) Eng C.C. for Harris C.C. in W_{x6}	4.43	3.39	9.6	10.6	Craze	Craze
11	M_3	.85	.61	12.17	11.94	Fits	Fits
	(W_{x8}) Eng C.C. for Harris C.C. in M_3	.03	.04	9.95	11.8	Craze	Craze

DISCUSSION

Mr. E. T. Montgomery: I have noticed so often in connection with descriptions of the preparation of bodies for dry-press work, that the statement is made that after filter-pressing, the body was dried, then 10 percent of water was added and the body pulverized ready for use.

We all know that dry scrap added to the blunger in any considerable quantity makes a short body. We also know that a previous complete drying at the temperature of our dryers reduces the plasticity of the body. I would therefore suggest that in order to retain the full initial plasticity of the body, the clay be taken from the dryer before it has reached a completely dry state and while it still contains the proper amount of water for pulverizing and use on the presses. I have used this method in the manufacture of dry-pressed porcelain and find that it gives better results than are obtained if the body is allowed to completely dry out, necessitating the further addition of water.

Prof. Pence: I might say that the difficulty in a case of that sort is to be sure that you are getting a constant water content. If you use the clay partially dry, you are never certain as to just how much water there is in it; and since the amount of moisture in a dry-pressed body affects the results very materially, it is desirable to use a system which affords an accurate control.

Mr. Simcoe: I may say, in reference to what Professor Pence has just said, that I think you can be just as accurate in taking the clay from the dryer, because when the water is added to the clay after it has been dried hard, the dust would have to be left some time to age, as it were, in order to allow the water to penetrate all through. So by the time it is ready for the presser, I don't see how you are going to positively know that the 10 percent of moisture is there, while the men, in taking the clay from the dryer, became pretty clever in knowing just when the right amount of moisture is there. In a practical way, it is better to take the clay from the dryer with the moisture in it than it is to use a body that has been wet down and pulverized,

I know of only one electric porcelain plant that reduces their clay body to dryness, then pulverize it between the rolls. After-

wards, the powder is placed in plaster-lined boxes, the plaster having previously been wetted. By this method, the body absorbed water from the wet plaster very uniformly. This process has the advantage of being less expensive to pulverize as compared with the method suggested by Mr. Montgomery; i. e., grinding the clay before it is thoroughly dry. The wet clay going into the grinder (disintegrator or blower) has a tendency to pack at the inner circumference of the shell and act as a brake, causing enormous wear on the spider as well as consuming unnecessary horsepower.

Mr. Barringer: I think adding the water to the dry clay is more or less of an academic precaution that is more than offset by the differences that would be encountered in handling that clay. You may very accurately take your dry clay and very accurately add your water, but, as has been pointed out, all through the processes of the shop that water will vary, and I very emphatically favor having the wet clay to start with and drying it down until it is given the proper consistency, and pressing from that. Moreover, the operators themselves will not use clay of the same consistency; you cannot expect it; one design will require a comparatively dry body and the next design may be radically different and require comparatively moist body. So I think the proposition of using dry clay and adding a definite amount of water is a precaution more than over-balanced by those other differences.

Mr. Purdy: I would like to ask the experience as to the content of moisture; in a dry pressed ware, is it 10 per cent, for instance, the best moisture content?

Prof. Pence: That figure was adopted as a logical basis of uniformity in this investigation and is not offered as the best amount in any given case.

Mr. Simcoe: A big and vital feature of this paper is being lost, namely, *the substituting of one material for another in a body.* Professor Staley emphasized the value of investigations along this line in enameled iron work.

To be specific, you have a body in which you use English ball clay, English china clay, and Florida clay.

BODY BATCH WEIGHT	
Spar	20
Flint	20
Eng. ball	20
English China	20
Fla. clay	20
	100

CLAY SUBSTANCE			Percent
Eng. ball	20	or	$33\frac{1}{3}$
Eng. china	20	or	$33\frac{1}{3}$
Fla. clay	20	or	$33\frac{1}{3}$
	60		100

Suppose we were unable to get any of the above clays, and were compelled to use Georgia china clay and Kentucky ball clay. Having figured the total clay substance at 100, we make a mix of $33\frac{1}{3}$ percent English ball, $33\frac{1}{3}$ percent English china, $33\frac{1}{3}$ Florida clay.

After blunging and reducing water content to 10 per cent, samples are dust pressed in any convenient form for comparison, glazed and fired. These samples will show exactly the resultant of the combined clays that go into your body and show shrinkage, vitrification and color, the glaze bringing out iron spots.

A series of mixes of Kentucky ball and Georgia china may be run to duplicate the above sample. We may not be able to get all the characteristics duplicated with the two clays. All other points may be O. K., but the shrinkage may be too great and additions of flint and whiting may give just what is needed.

To illustrate say:

			Percent
Kentucky ball	40	or	24.0
Georgia china	40	or	24.0
Flint	19	or	11.4
Whiting	1	or	0.6
	100		60.0

Substituting in the original body, we have

Spar	20.00
Flint 20 plus 11.4	31.40
Kentucky ball	24.00
Georgia china	24.00
Whiting	0.6
Total	100.00

The foregoing is purely a hypothetical case; and I wish to strongly emphasize the necessity of each potter making his own

substitution table. Any data that might be compiled would only be valuable as a guide.

Synthetic ball clays and china clays may be made satisfactorily by this process. I have succeeed in making, out of a white-burning New Jersey sagger clay and other materials, a cheap substitute for English ball clay having exactly the same color, plasticity, shrinkage and vitrification.

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